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FIELD OPERATIONS GUIDE FOR AUTOMATIC AIR MONITORING EQUIPMENT

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PREPARED BY

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ENVIRONMENTAL PROTECTION AGENCY
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RESEARCH TRIANGLE PARK,
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16. Abstracts
A guide to State and local air pollution control agencies in the selection, installation, and operation of automatic monitoring equipment is presented. The discussion is limited to suspended particulates, carbon monoxide, hydrocarbons, nitrogen dioxide, photochemical oxidants, ozone, and sulfur dioxide. Essentially a state-of-the-art treatise on automated equipment, this guide covers: Selecting the number and location of sampling stations; shelter design; instrumentation specifications; calibration; installation of equipment; routine operation; maintenance; and data logging. The detail is of value to administrative and technical personnel. Installation and operating costs, and personnel requirements necessary to determine the extent of the monitoring program consistent with budgetary limitations and the need for air quality data are included. Sufficient detail is provided concerning equipment specifications and operating characteristics to serve as an operations handbook for technical personnel.

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Technical Center
Research Triangle Park, North Carolina

July 1971

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FIELD OPERATIONS GUIDE FOR AUTOMATIC AIR MONITORING EQUIPMENT

1.0 INTRODUCTION

Surveillance of air quality is an important function of any air pollution control agency. Initially the agency must determine the magnitude and scope of its air pollution problem, i.e., the extent to which air quality standards are being exceeded. This data may then be used to develop an effective emission control plan. Following the adoption of emission regulations, atmospheric surveillance is required to evaluate the progress toward the attainment of air quality standards. Additionally, for those areas prone to the occurrence of periods of high air pollution (episodes), surveillance becomes a vital part of the Emergency Action Plan.

To fulfill the requirements for air quality data, as determined by the implementation plan, most control agencies find it necessary to measure the ambient concentrations of pollutants at a number of sampling sites strategically located through the area. At many sampling sites, especially where the air quality standards are unlikely to be exceeded, intermittent 24-hour integrated measurements suffice. However, within most regions it is necessary to make continuous measurements of pollutant concentrations at one or more sampling locations. This document is intended as a guide to State and local air pollution control agencies (hereafter referred to as agency) in the selection, installation, and operation of automatic monitoring equipment.

1.1 Objectives and Scope

Air pollution control agencies at all levels of government are now conducting atmospheric monitoring activities to measure a wide range of particulate and gaseous pollutants. A survey of these activities indicates that the pollutants most likely to be included in the monitoring activities are particulates (both suspended and settleable); carbon monoxide; hydrocarbons (total, methane); photochemical oxidants corrected for NO_2 and SO_2; ozone; oxides of nitrogen (NO and NO_2); and sulfur dioxide and sulfation rates. This list of pollutants coincides with the list of pollutants for which criteria and, in most cases, control technology documents have been published. Of this list the administration of the Environmental Protection Agency has established National Air Quality Standards for SO_2, NO_2, particulate matter, CO, photochemical oxidants corrected for NO_2 and SO_2, and hydrocarbons corrected for methane.

This document presents a summary of the experience gained by control agencies and other selected users over a number of years through the operation of automated monitoring equipment. Thus, the discussion is limited to suspended particulates, carbon monoxide, hydrocarbons, nitrogen dioxide, photochemical oxidants, ozone, and sulfur dioxide. The document is essentially a state-of-the-art treatise on automated equipment covering such things as:

- Selecting the number and location of sampling stations
- Shelter design
- Instrumentation specifications
- Calibration
- Installation of equipment
- Routine operation
- Maintenance
- Data logging

The detail in which the techniques and procedures are presented is intended to be of value to administrative and technical personnel. It provides the agency with information concerning installation and operating costs, and personnel requirements necessary to determine the extent of the monitoring program consistent with budgetary limitations and the need for air quality data. The document also provides sufficient detail concerning equipment specifications and operating characteristics to serve as an operations handbook for technical personnel.

1.2 Role of Air Quality Monitoring

The need for adequate air quality data is important in the development of implementation plans for controlling air pollution in Air Quality Control Regions. Initially, air quality measurements are required to establish the extent by which air quality standards are currently being exceeded and to establish a basis from which control programs are formulated. Once a plan for controlling pollutant emissions has been developed and adopted, air quality data is one of the requirements for documenting progress toward the attainment of standards. Finally, air quality monitoring is necessary to provide immediate information during adverse meteorological conditions as required in an Emergency Action Plan.

The Clean Air Act of 1970 stresses the importance of air quality surveillance as an integral part of the States' implementation plan. Specifically Section 110(a)(2)(C) of the Act requires that,

> "it [the implementation plan] includes provision for establishment and operation of appropriate devices, methods, systems, and procedures necessary to (i) monitor, compile, and analyze data on ambient air quality and, (ii) upon request, make such data available to the Administrator;"

Recently, the Environmental Protection Agency[1] has summarized the objectives of air quality monitoring. Air quality surveillance within a region must provide information to be used as a basis for the following actions:

(a) To judge compliance with and/or progress made toward meeting ambient air quality standards.

(b) To activate emergency control procedures to prevent air pollution episodes.

(c) To observe pollution trends throughout the region including the nonurban areas. (Information on the nonurban areas is needed to evaluate whether air quality in the cleaner portions of a region is deteriorating significantly and to gain knowledge about background levels.)

(d) To provide a data base for application in evaluation of effects; urban, land use, and transportation planning; development of abatement strategies; and development and validation of diffusion models.

2.0 DESIGN OF AUTOMATIC MONITORING SYSTEM

2.1 Number of Monitoring Sites

Criteria for determining the number of monitoring sites required for adequate surveillance in an Air Quality Control Region will be published in a forthcoming Federal Register, by the Environmental Protection Agency. The criteria are based upon the priority (I, II, III) assigned to a region.

A priority classification has been assigned to each AQCR for CO, NO_2, particulate matter, photochemical oxidants, and sulfur dioxide according to the criteria presented in Table 1. For particulate matter and sulfur oxides the classification criteria provide for priorities of I, II, or III, while for CO, NO_2, and photochemical oxidants priorities of either I or III are assigned to a region.

The minimum requirements for the establishment of an air quality monitoring system based upon the priority classification of a region are presented in Table 2. One or more monitoring sites are required for each of the five pollutants in a priority I region. For regions classified as priority II or III, the minimum requirements provide for monitoring suspended particulates and sulfur dioxide only with 24-hour sampling every 6 days.

2.2 Site Selection

Although few sites are ideally located for all pollutants, most agencies, for purely economic reasons, find it necessary to consolidate sampling equipment for a number of pollutants at each sampling site. Within this restriction, the factors which most affect site selection are: geographical distribution of population, location of pollutant emission sources, meteorology, and topography.

Table 1. CRITERIA FOR CLASSIFICATION OF AIR QUALITY CONTROL REGIONS

Concentrations in micrograms per cubic meter (ppm in parentheses)

Pollutant	Priority		
	I	II	III
Sulfur Oxides			
annual arithmetic mean	>100 (.04)	60-100 (.02-.04)	< 60 (.02)
24-hour maximum	>455 (.17)	260-455 (.10-17)	< 260 (.10)
3-hour maximum		>1300 (.50)	<1300 (.50)
Particulate matter			
annual geometric mean	> 95	60-95	< 60
24-hour maximum	>325	150-325	< 150
Carbon monoxide			
8-hour maximum	≥ 14^a (12)		< 14^a (12)
1-hour maximum	≥ 55^a (48)		< 55^a (48)
Nitrogen dioxide			
annual arithmetic mean	≥110 (.06)		< 110 (.06)
Photochemical oxidants			
1-hour maximum	≥195 (.10)		< 195 (.10)

[a] Concentration in milligrams per cubic meter.

Table 2. RECOMMENDED NUMBER OF AIR QUALITY MONITORING SITES

Regional classification	Pollutant	Measurement method^{i}	Region population	Minimum number of air quality monitoring sites^{a}	Minimum frequency of sampling
I	Suspended particulates	High volume sampler	Less than 100,000	4	One 24-hour sample every 6 days^{c}
			100,000-1,000,000	4 + 0.6 per 100,000^{b}	
			1,000,000-5,000,000	7.5 + 0.25 per 100,000^{b}	
			Above 5,000,000	12 + 0.16 per 100,000^{b}	
		Tape sampler	--	One per 250,000^{b} up to 8 sites	One sample every 2 hours
	Sulfur dioxide	Pararosaniline or equivalent	Less than 100,000	2	One 24-hour sample every 6 days (gas bubbler)^{c}
			100,000-1,000,000	2.5 + 0.5 per 100,000^{b}	
			1,000,000-5,000,000	6 + 0.15 per 100,000^{b}	
			Above 5,000,000	11 + 0.05 per 100,000^{b}	
			Less than 100,000	1	Continuous
			100,000-5,000,000	1 + 0.15 per 100,000^{b}	
			Above 5,000,000	6 + 0.05 per 100,000^{b}	
	Carbon monoxide	Nondispersive infrared or equivalent^{e}	Less than 100,000	1	Continuous
			100,000-5,000,000	1 + 0.15 per 100,000^{b}	
			Above 5,000,000	6 + 0.05 per 100,000^{b}	
	Photochemical oxidants	Gas phase chemiluminescence or equivalent^{f}	Less than 100,000	1	Continuous
			100,000-5,000,000	1 + 0.15 per 100,000^{b}	
			Above 5,000,000	6 + 0.05 per 100,000^{b}	
	Nitrogen dioxide	24-hour sampling method (Jacobs-Hochheiser method)	Less than 100,000	3	One 24-hour sample every 14 days (gas bubbler)^{g}
			100,000-1,000,000	4 + 0.6 per 100,000^{b}	
			Above 1,000,000	10	

Table 2 (continued). RECOMMENDED NUMBER OF AIR QUALITY MONITORING SITES

Regional classification	Pollutant	Measurement method[i]	Region population	Minimum number of air quality monitoring sites[a]	Minimum frequency of sampling
II	Suspended particulates	High volume sampler	--	3	One 24-hour sample every 6 days[c]
		Tape sampler	--	1	One sample every 2 hours
	Sulfur dioxide	Pararosaniline	--	3	One 24-hour sample every 6 days (gas bubbler)[c]
			--	1	Continuous
III[h]	Suspended particulates	High volume sampler	--	1	One 24-hour sample every 6 days[c]
	Sulfur dioxide	Pararosaniline	--	1	One 24-hour sample every 6 days (gas bubbler)[c]

[a] In interstate regions, the number of sites required should be prorated to each State on a population basis.

[b] Total population of a region. When required number of samplers includes a fraction, round off to nearest whole number.

[c] Equivalent to 61 random samples per year.

[d] Equivalent methods are (1) Gas Chromatographic Separation-Flame Photometric Detection (provided Teflon is used throughout the instrument system in parts exposed to the air stream), (2) Flame Photometric Detection (provided interfering sulfur compounds present in significant quantities are removed), (3) Coulometric Detection (provided oxidizing and reducing interferences such as O_3, NO_2, and H_2S are removed), and (4) the automated Pararosaniline Procedure.

[e] Equivalent method is Gas Chromatographic Separation - Catalytic Conversion - Flame Ionization Detection.

[f] Equivalent methods are (1) Potassium Iodide Colorimetric Detection (provided a correction is made for SO_2 and NO_2), (2) UV Photometric Detection of Ozone (provided compensation is made for interfering substances), and (3) Chemiluminescence Methods differing from that of the reference method.

Table 2 (continued). RECOMMENDED NUMBER OF AIR MONITORING SITES

FOOTNOTES (continued)

[g] Equivalent to 26 random samples per year.

[h] It is assumed that the Federal motor vehicle emission standards will achieve and maintain the national standards for carbon monoxide, nitrogen dioxide, and photochemical oxidants; therefore, no monitoring sites are required for these pollutants.

[i] All measurement methods, except the Tape Sampler method, are described in the national primary and secondary ambient air quality standards published in the Federal Register on April 30, 1971 (36 F.R. 8186). Other methods together with those specified under footnotes (d), (e), and (f) will be considered equivalent if they meet the following performance specifications:

	Pollutants		
Specification**	Sulfur dioxide	Carbon monoxide	Photochemical oxidant*
Range	0-2620 $\mu g/m^3$ (0-1 ppm)	0-58 mg/m^3 (0-50 ppm)	0-880 $\mu g/m^3$ (0-0.5 ppm)
Minimum detectable sensitivity	26 $\mu g/m^3$ (0.01 ppm)	0.6 mg/m^e (0.5 ppm)	20 $\mu g/m^3$ (0.01 ppm)
Rise time, 90%	5 min.	5 min.	5 min.
Fall time, 90%	5 min.	5 min	5 min.
Zero drift	± 1% per day and ± 2% per 3 days	± 1% per day and ± 2% per 3 days	± 1% per day and ± 2% per 3 days
Span drift	± 1% per day and ± 2% per 3 days	± 1% per day and ± 2% per 3 days	± 1% per day and ± 2% per 3 days
Precision	± 2%	± 4%	± 4%
Operation period	3 days	3 days	3 days
Noise	± 0.5% (full scale)	± 0.5% (full scale)	± 0.5% (full scale)
Interference equivalent	26 $\mu g/m^3$ (0.01 ppm)	1.1 mg/m^3 (1 ppm)	20 $\mu g/m^3$ (0.01 ppm)
Operating temperature fluctuation	± 5° C	± 5° C	± 5° C
Linearity	2% (full scale)	2% (full scale)	2% (full scale)

(continued)

Table 2 (continued). RECOMMENDED NUMBER OF MONITORING SITES

FOOTNOTES (continued)

[*] Corrected for NO_2 and SO_2.

[**] These specifications are defined below and in Section 6.0:

Range: The minimum and maximum measurement limits.

Minimum detectable sensitivity: The smallest amount of input concentration which can be detected as concentration approaches zero.

Rise time 90%: The interval between initial response time and time to 90% response after a step increase in inlet concentration.

Fall time 90%: The interval between initial response time and time to 90% response after a step decrease in the inlet concentration.

Zero drift: The change in instrument output over a stated time period of unadjusted continuous operation, when the input concentration is zero.

Span drift: The change in instrument output over a stated period of unadjusted continuous operation, when the input concentration is a stated upscale value.

Precision: The degree of agreement between repeated measurements of the same concentration (which shall be the midpoint of the stated range) expressed as the average deviation of the single results from the mean.

Operation period: The period of time over which the instrument can be expected to operate unattended within specifications.

Noise: Spontaneous deviations from a mean output not caused by input concentration changes.

Interference equivalent: The portion of indicated concentration due to the total of the interferences commonly found in ambient air.

Operating temperature fluctuation: The ambient temperature fluctuation over which stated specifications will be met.

Linearity: The maximum deviation between an actual instrument reading and the reading predicted by a straight line drawn between upper and lower calibration points.

2.2.1 Population Density

The most obvious location for a continuous monitoring station is in the central business section of a city. In many cases this site not only reflects the contribution of sources throughout the city, but also provides an indication of the pollution dosage to which large numbers of people are exposed. If more than one continuous monitoring station is to be installed, other areas in the city with high population density should be considered. Population density maps are usually available from official planning agencies in the area. In selecting an area of the city on the basis of dense population, consideration should also be given to the location of pollution sources. It is always best if a sampling site fulfills more than one objective.

2.2.2 Location of Emission Sources

Generally the reason for locating a continuous monitoring station is to obtain representative data for an area; therefore, it is important that the site is not unduly affected by a dominant point source. One suggested criterion is that where multiple sources exist, "no single source should contribute more than five percent of the quantity of the contaminant being measured".[3] The station should not be located in the downwash (the downward motion of air due to the lower pressure on the lee side of a structure) of an adjacent building--generally no closer than twice the height of the building.

2.2.3 Meteorology

The ability of the atmosphere to transport and diffuse air pollutants is dependent upon a number of meteorological parameters such as wind speed and direction, atmospheric stability, mixing depth, etc. From the standpoint of site selection, wind speed and direction are probably most important since they tend to describe the general movement of air masses through the area.

For most regions the only meteorological data available are those from the local airport weather station. Such data are of prime importance to provide information about macroscale weather systems. Air pollution meteorologists tend to agree that meteorological conditions at the local airport are not representative of the microscale meteorology throughout the region. Because of this, many control agencies include meteorological instrumentation at one or more continuous air monitoring stations. It is strongly recommended that an agency which lacks detailed meteorological data for candidate locations for continuous monitoring sites should consult a meteorologist before making final site selections.

2.2.4 Topography

For any land area, microscale meteorological conditions are significantly affected by topographical features such as steep valleys and prominent hills. In urban areas the situation is further complicated by the grouping of buildings and structures, the location of streets and highways, and the heat island effect. The probable effect of topography on the transport of pollutants from major point sources to candidate monitoring sites must be determined.

2.2.5 Site Description

A detailed description should be prepared for each monitoring site. The availability of such information will be of considerable value in the interpretation of data obtained at a given site.

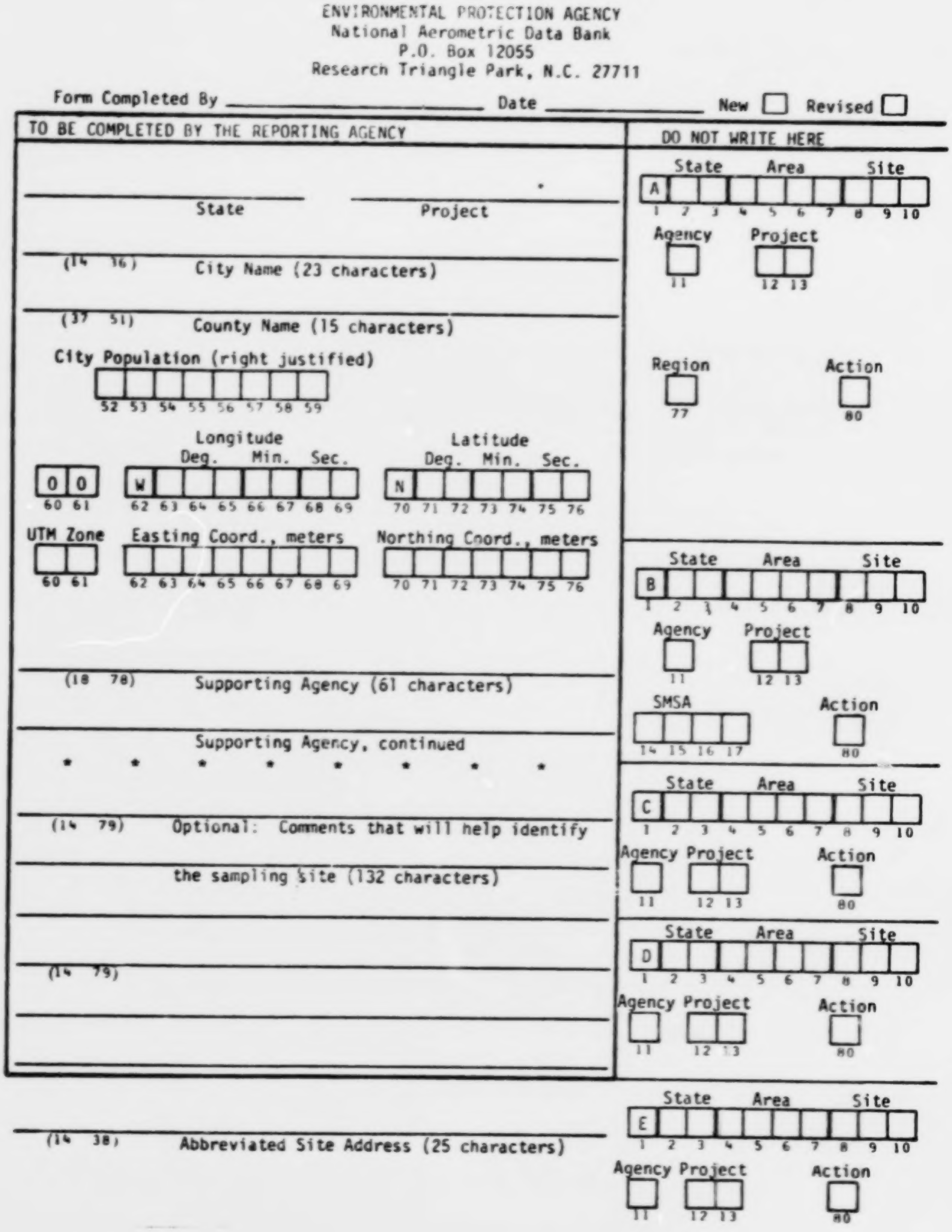
Furthermore, a site description may provide for a better comparison of results between sites within a region or between regions.

All control agencies which submit air quality data to the National Aerometric Data Bank are required to use the SAROAD system (Storage and Retrieval of Aerometric Data).[4] SAROAD is designed to permit rapid retrieval of air quality measurements made anywhere in the United States and consists of (1) comprehensive identification codes for stations and pollutants, (2) a set of data reporting forms to accommodate the variety of sampling and analysis procedures and facilitate the transfer of data to punch cards, input programs and the resulting data file, and (3) output programs used to list, summarize, and analyze the stored data (Figure 1). This form provides detailed information about location including address and grid coordinate (Universal Transverse Mercator), name of operating agency, and pertinent information about the type of area in which the site is located.

It is also recommended that each monitoring site be classified according to its exposure to pollution, including motor vehicle emissions. Therefore each site should be assigned to one of the appropriate categories as listed below:

Category A. Heavy concentration--high potential for pollutant buildup. Site 10-15 feet from major traffic artery with local terrain features restricting ventilation. Sampler probe 10-15 feet above ground.

Category B. Heavy concentration--minimal potential for pollutant buildup. Site 15-50 feet from major traffic artery with good natural ventilation. Sampler probe 10-15 feet above ground.



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National Aerometric Data Bank
P.O. Box 12055
Research Triangle Park, N.C. 27711

Form Completed By ____________________ Date ______________ New ☐ Revised ☐

TO BE COMPLETED BY THE REPORTING AGENCY

State ______________ Project ______________

(14 36) City Name (23 characters)

(37 51) County Name (15 characters)

City Population (right justified) ☐☐☐☐☐☐☐☐ 52 53 54 55 56 57 58 59

0 0 (60 61)

Longitude Deg. Min. Sec. W☐☐☐☐☐☐☐ 62 63 64 65 66 67 68 69

Latitude Deg. Min. Sec. N☐☐☐☐☐☐☐ 70 71 72 73 74 75 76

UTM Zone ☐☐ 60 61

Easting Coord., meters ☐☐☐☐☐☐☐☐ 62 63 64 65 66 67 68 69

Northing Coord., meters ☐☐☐☐☐☐☐ 70 71 72 73 74 75 76

(18 78) Supporting Agency (61 characters)

Supporting Agency, continued

* * * * * * * *

(14 79) Optional: Comments that will help identify the sampling site (132 characters)

(14 79)

(14 38) Abbreviated Site Address (25 characters)

DO NOT WRITE HERE

State Area Site A☐☐☐☐☐☐☐☐☐ 1 2 3 4 5 6 7 8 9 10

Agency ☐ 11 Project ☐☐ 12 13

Region ☐ 77 Action ☐ 80

State Area Site B☐☐☐☐☐☐☐☐☐ 1 2 3 4 5 6 7 8 9 10

Agency ☐ 11 Project ☐☐ 12 13

SMSA ☐☐☐☐ 14 15 16 17 Action ☐ 80

State Area Site C☐☐☐☐☐☐☐☐☐ 1 2 3 4 5 6 7 8 9 10

Agency ☐ 11 Project ☐☐ 12 13 Action ☐ 80

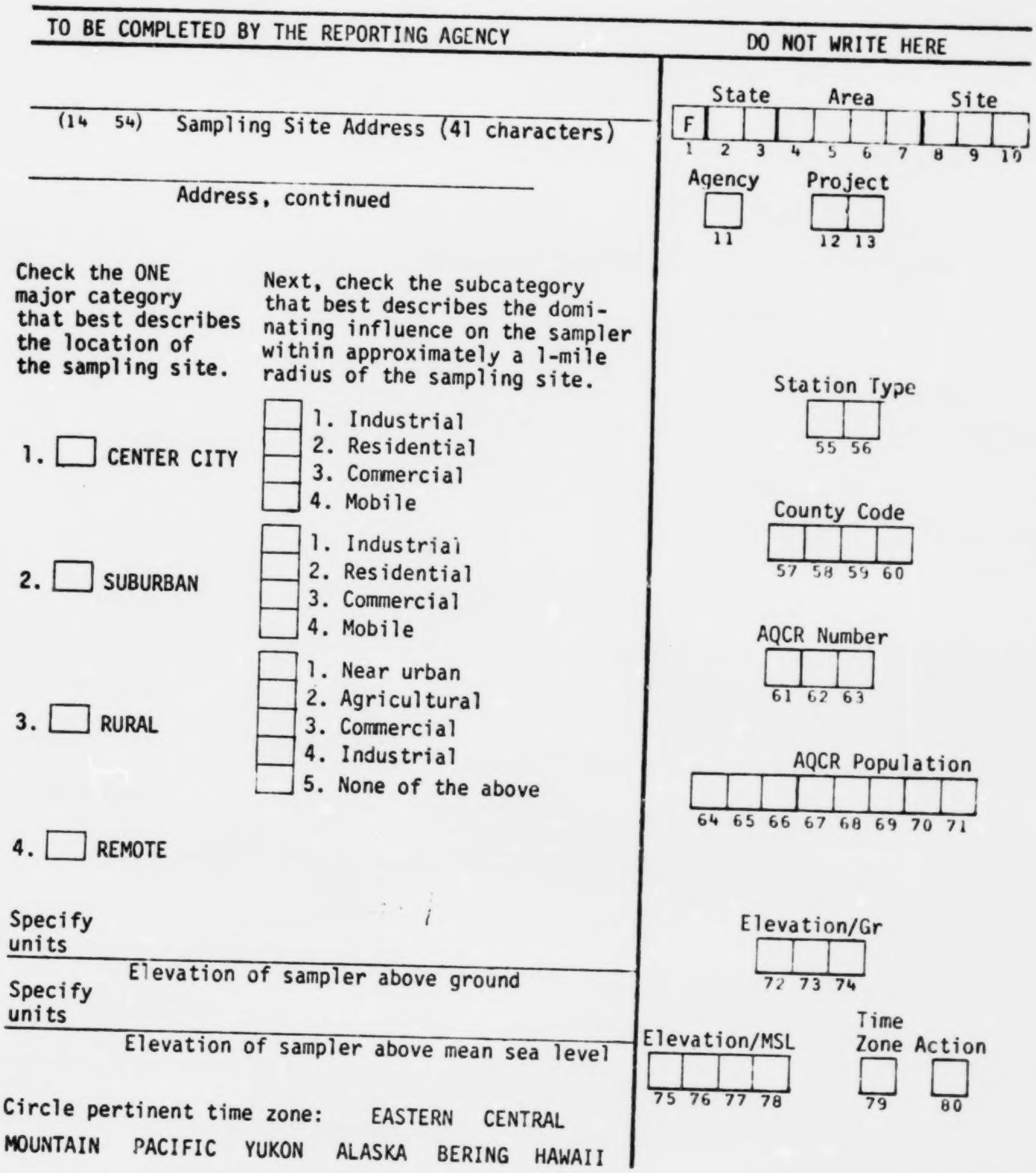
State Area Site D☐☐☐☐☐☐☐☐☐ 1 2 3 4 5 6 7 8 9 10

Agency ☐ 11 Project ☐☐ 12 13 Action ☐ 80

State Area Site E☐☐☐☐☐☐☐☐☐ 1 2 3 4 5 6 7 8 9 10

Agency ☐ 11 Project ☐☐ 12 13 Action ☐ 80

Figure 1. SAROAD site identification form (front).



TO BE COMPLETED BY THE REPORTING AGENCY

(14 54) Sampling Site Address (41 characters)

Address, continued

Check the ONE major category that best describes the location of the sampling site.

Next, check the subcategory that best describes the dominating influence on the sampler within approximately a 1-mile radius of the sampling site.

1. ☐ CENTER CITY
   - ☐ 1. Industrial
   - ☐ 2. Residential
   - ☐ 3. Commercial
   - ☐ 4. Mobile

2. ☐ SUBURBAN
   - ☐ 1. Industrial
   - ☐ 2. Residential
   - ☐ 3. Commercial
   - ☐ 4. Mobile

3. ☐ RURAL
   - ☐ 1. Near urban
   - ☐ 2. Agricultural
   - ☐ 3. Commercial
   - ☐ 4. Industrial
   - ☐ 5. None of the above

4. ☐ REMOTE

Specify units ____________
Elevation of sampler above ground

Specify units ____________
Elevation of sampler above mean sea level

Circle pertinent time zone: EASTERN CENTRAL MOUNTAIN PACIFIC YUKON ALASKA BERING HAWAII

DO NOT WRITE HERE

State ☐F ☐☐ (1 2 3) Area ☐☐☐☐ (4 5 6 7) Site ☐☐☐ (8 9 10)

Agency ☐ (11) Project ☐☐ (12 13)

Station Type ☐☐ (55 56)

County Code ☐☐☐☐ (57 58 59 60)

AQCR Number ☐☐☐ (61 62 63)

AQCR Population ☐☐☐☐☐☐☐☐ (64 65 66 67 68 69 70 71)

Elevation/Gr ☐☐☐ (72 73 74)

Elevation/MSL ☐☐☐☐ (75 76 77 78)

Time Zone ☐ (79) Action ☐ (80)

Figure 1 (continued). SAROAD site identification form (back).

Category C. Medium concentration. Site 50-200 feet from major traffic artery. Sampler probe 10-15 feet above ground.

Category D. Low concentration. Site 200 feet or more from traffic artery. Sampler probe 10-15 feet above ground.

Category E. Air Mass Station. Sampler probe is greater than 15 feet above ground. Two subclasses: (1) good exposure from all sides (e.g. on top of building), and (2) directionally biased exposure (probe extended from window).

Category F. Poor site--adjacent to point source, bad terrain, etc.; yields biased data not directly relatable to air quality standards.

2.3 Shelter Design

There is no single ideal shelter design for a remote air sampling station. The ultimate design depends on many factors including climate, neighborhood, equipment design, and agency needs. Rather than specifying a standard shelter, this section will provide a master checklist of design considerations to assist in the development of cost estimates and specifications to meet individual requirements.

2.3.1 Mobility

The mobile capabilities of shelters are dictated by overall program objectives. If it is anticipated that the station will be at a single location for many years, it would seem unnecessary to purchase a mobile shelter. However, city characteristics may change with time and the station may need to be relocated to reflect shifting population or industrial patterns. There is a point at which a decision to require shelter mobility must be made. The Agency must first decide how the facility is to be used. This decision will fix many of the design alternatives.

2.3.2 Neighborhood Factors

Owing to the potential public relations value of a remote air sampling station, it is important that the shelter does not disrupt the neighborhood or other surroundings. Where the shelter is to be located in a residential or rural area, aesthetics should be considered. For example, a trailer may be objectionable in a residential neighborhood but acceptable in an industrial area. The color of the paint may be obtrusive. Restraint and good judgement should be exercised in the use of exterior paint and signs. The noise from high volume samplers should also be considered.

The character of the neighborhood will also dictate the use of materials and related construction details. Consider the impracticability of having windows in neighborhoods which experience high incidences of vandalism and theft. Heavy industrial areas may not present security problems so much as accidental breakage. If windows are used, the use of unbreakable clear plastics, in lieu of glass, should be considered.

The unavailability or high cost of desirable space and/or the high incidence of theft or vandalism in certain neighborhoods make it impractical to locate the monitoring station in a freestanding shelter. The use of limited access public buildings such as schools or fire stations should be investigated in these cases.

2.3.3 Physical Requirements

Preliminary consideration of the physical requirements inherent with the design, construction, and use of the remote sampling station will ultimately result in a configuration which will most efficiently meet the specific needs of the agency. The following considerations, in this respect, should be made.

2.3.3.1 General Design. The shelter specifications must also spell out the necessary appurtenances. These include foundation, running gear, stabilizing jacks, equipment platform, ladder, and other items. Remember that equipment must fit through at least one doorway. Where applicable, standard construction material dimensions should be kept in mind when designing the shelter. As far as practical, the design should be maintenance-free. Since the shelter is small, the material costs will generally be slight compared to the labor involved. Therefore, the use of high grade materials will not appreciably affect the overall cost. On the other hand, rapid deterioration of the shelter will result in costly maintenance and loss of public relations value.

Standard construction methods should not be overlooked. While modular semipermanent structures may seem practical, they are costly. The added initial cost is offset if the shelter is moved periodically. However, if a station is planned to be a fixed location, consider a permanent building. Standard construction methods can result in not only less initial cost, but less maintenance as well.

2.3.3.2 Space Requirements. Space will be dependent upon the specific needs of the Agency. In most cases where the remote station is used without additional support laboratory facilities, additional space will be required. Mobile facilities are somewhat limited in space and this should be considered. In general a self-sustaining remote air sampling station will require, as a minimum, the following space:

Instrumentation and laboratory area	150 sq. ft.
Work area (desk and sink)	30
Compressed gas cylinder storage	15
Miscellaneous storage	10
Toilet facilities	15
	220 sq. ft.

See Figure 2 for a suggested layout. In addition, an elevated surface of approximately 40 square feet is required for related sampling equipment. This equipment may include a meteorological package complete with a retractable tower, a hi-vol sampler, and static devices such as the dustfall bucket and sulfation plate. This area should have limited access by either stairs or a ladder. This space can be either the building roof or a separate structure. Note, however, that where the roof space is to be utilized, suitable roofing materials and structural support must be provided.

2.3.3.3 Materials Requirements. This section will give the reader a general idea of suitable materials for the shelter; however, detailed specifications are not within the scope of this manual. Table 3 presents the types of materials suitable for each of the major elements of the various shelters. In some instances where alternatives are available, more than one material is listed.

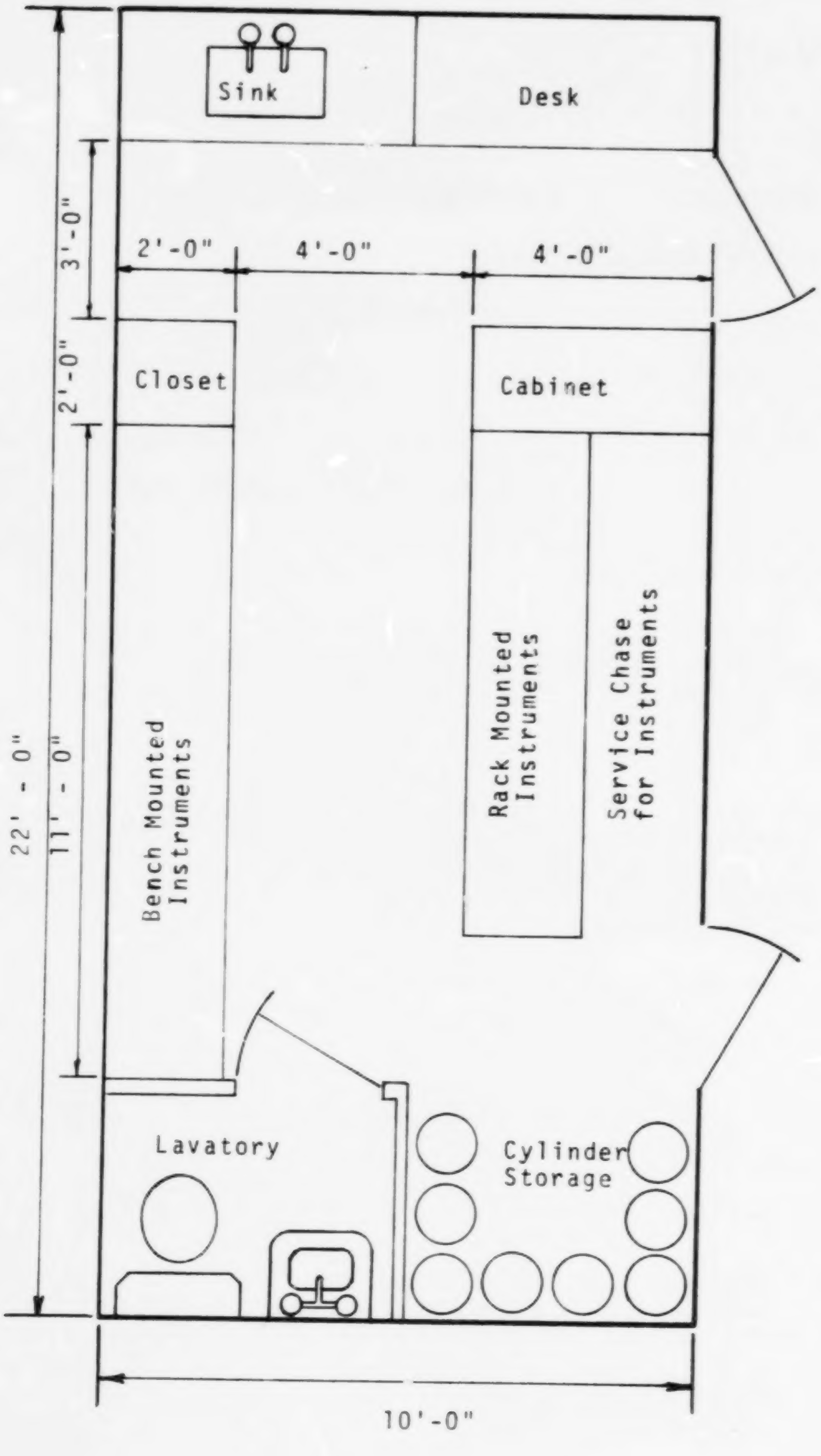

Sink
Desk
3'-0"
2'-0"
4'-0"
4'-0"
2'-0"
Closet
Cabinet
22' - 0"
11' - 0"
Bench Mounted Instruments
Rack Mounted Instruments
Service Chase for Instruments
Lavatory
Cylinder Storage
10'-0"

Figure 2. Floor plan, remote air sampling station.

Table 3. MATERIALS USED IN SHELTER CONSTRUCTION

Element	Type of Shelter		
	Mobile	Prefabricated	Conventional
Foundation	Gravel pad Concrete pad	Concrete piers or blocks	Concrete footings
Floor structure	Steel Wood	Steel Wood	Concrete
Finished flooring	Vinyl Asbestos tile Carpet	Vinyl Asbestos tile Carpet	Vinyl Asbestos tile Concrete Carpet
Wall structure	Steel Wood	Wood	Wood Masonry
Outside wall finish	Aluminum	Plywood Finished plywood	Plywood Masonry
Inside wall finish	Finished plywood	Finished plywood Drywall Plaster	Finished plywood Plaster Masonry
Roof structure	Steel Wood	Wood	Bar joist Wood Concrete
Roofing membrane	Aluminum	Builtup Rubber Smooth asphalt	Builtup Rubber Smooth asphalt
Finished ceiling	Acoustical tile	Acoustical tile	Acoustical tile Plaster Exposed bar joist
Insulation	Fiberglass	Foilbacked fiberglass batts	Foilbacked fiberglass batts

Additionally, specifications are required for certain minor items. As was previously stated, where windows are desirable, a high grade clear acrylic is suggested in lieu of glass. In many respects a skylight can achieve the same psychological affect as a window and therefore should not be overlooked. However, natural light may affect the chemical reaction in certain monitoring instruments. Where such instruments are used, it is advisable to exclude all natural light. If the shelter roof is planned to be used as a working surface, specify a material suitable for pedestrian traffic to be installed over the roofing membrane. This material will vary according to the type of membrane used.

Quality of the materials should also be considered. As was previously stated, the shelter should be as maintenance-free as possible. Two items that are often overlooked in this regard are the doors and the hardware. Specify a high quality door which is designed for exterior use. Either solid wood or metal can give years of trouble-free service. Likewise the door hardware should be of high quality. Since the hardware should be of high quality, the standard hardware found in many of the newer office complexes and residences is not recommended. If the proper door is used, it will be heavy; therefore, three or possibly four ball-bearing-type hinges should be used for each door. The door should be protected with adequate kick plates and push plates--especially where equipment is to be moved in and out. Door closers should be of adequate size, allowing for wind loads on exterior doors. Finally, the lockset should be a heavy duty mortise type. The lockset function would normally be "Inside open at all times;

lock with thumblatch on inside; unlock outside with key." Note that all shelters should be on the same key system, either keyed alike or master keyed. Generally all locks used on the doors of any one shelter should be keyed alike.

2.3.3.4 Electrical Requirements. Owing to the nature of the air sampling station, it is important that adequate power be supplied to the shelter. Total required power depends on the quantity and type of equipment to be used. In general 240-volt single-phase service is required for air conditioning and a water still. Both the air conditioning unit and the still will generally require separate 30-ampere circuits. Whether 240-volt service is required for any other purpose depends on the instruments used. It is unlikely that the instruments will require more than 120-volt service. Individual circuit breakers should be provided for all instruments. Typical electrical requirements for a remote air sampling station are shown in Table 4. Total service requirement should be single-phase, three-wire, 105 amperes at 240-volts. This requires a No. 2 service entrance cable. The load center should have a 125-ampere main with 16 spaces. This will provide six spare spaces for use in the event that 240-volt equipment is added.

Since the instrumentation is adversely affected by voltage fluctuations, it is recommended that all sophisticated instrumentation be powered by a regulated source. Pumps, lights, high-volume samplers, heaters and the like may be on nonregulated circuits. Since proper ampere loading is important for efficiency, a constant-voltage transformer such as one manufactured by Sola Electric Division, Sola Basic Industries, or equivalent, providing at least 30 amperes of regulated power is required.

Table 4. TYPICAL ELECTRICAL REQUIREMENTS FOR A REMOTE AIR SAMPLING STATION

Item	Quantity	Service	Comments
Air conditioner	1	240 V, 30 A, 1ø	
Still	1	240 V, 30 A, 1ø	
Lights	1 kW	120 V, 10 A, 1ø	Fluorescent; all on one circuit
Instruments (including roof outlets)	15 Duplex	120 V, 30 A, 1ø	Instruments plug into wall outlets
Hot water heater	1	120 V, 15 A, 1ø	
Pumps and misc.	10	120 V, 20 A, 1ø	

Exterior outlets should be located at the elevated work platform only. The added cost of installing ground level outlets is not warranted since ground-level equipment is seldom used. Electrical power at ground level can be supplied by means of extension cords. The outlets must be waterproof; use a NEMA watertight box. A telephone outlet should also be provided for.

Use electricity for heating purposes, even if gas or oil is available, since combustion processes will form pollutants which will adversely affect true ambient conditions.

Note that the requirements for electrical construction and inspection vary. In general, construction must follow the National Electric Code. Local codes may be more restrictive. Some may allow nonmetallic sheathed cable while others require the wiring to be put in metallic conduit. Prefabricated structures must often be inspected prior to installing the interior wall finish. Regardless of the standard wiring procedures used by the shelter manufacturer, the Agency must conform with State and local codes. Deficient specifications in this regard may result in a costly field change.

2.3.3.5 Plumbing Requirements. A remote air sampling station should have a laboratory-type sink. If water is not available or if it is not known where the stations are to be sited, provision should be made for water storage. Permanent shelters, however, should be self-sustaining.

Toilet facilities consisting of a water closet and lavatory are generally required; however, this is a costly item. Permanent stations may be able to utilize existing facilities nearby. Normally, if the station requires a full-time attendant, toilet facilities should be provided. Shelters having mobile capabilities should also have facilities for toilet hookup.

2.3.3.6 Noise Considerations. New instrumentation may not present a noise problem. However, older equipment may generate a considerable amount of pump noise. Noise should be kept at a minimum and in no case should be noise level at the attendant's desk exceed 65 dB on the A scale.* If pumps are unduly noisy, one solution lies in disconnecting the individual pumps and running all the instruments off a common isolated pump. Where this solution is used, a standby pump must be provided to avoid loss of data should the main pump fail. The standby pump should be activated automatically by means of a pressure switch in the vacuum line. An alternate solution would be to place a sound barrier between the attendant's work area and the instrument area or to isolate each pump in a second absorbing container.

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*Accoustical standards have been established pertaining to three weighing characteristics, designated A, B, and C. The A network discriminates against very low frequencies; therefore, it is employed to determine speech interference levels.

Sound absorbing materials are also helpful when used in the area in which the noise is generated. Acoustic tile is a good material to use on the ceiling while a practical type of synthetic fabric carpeting on the floor would be helpful.

2.3.3.7 Heating and Air Conditioning. Since the purpose of the station is to sample the ambient air, it is imperative that the station does not in any way affect the air quality; therefore, heating and cooling should be done electrically. This can be done by means of a heat pump or an air conditioning (cooling) unit with electric resistance heaters. The latter is recommended because of the higher maintenance required for heat pumps.

Air distribution within the shelter must be designed to prevent the air from blowing directly on the instruments. Even distribution, without drafts, is necessary.

2.3.3.8 Security. Security problems were alluded to in the previous discussions relative to windows, doors, and hardware. In some areas it may be desirable to maintain a night light inside the shelter and/or floodlighting outside the shelter. Additional security requirements may be desirable in the form of a perimeter fence. This is an item to be handled on a case-by-case basis.

2.3.3.9 Safety. Various safety regulations will apply to the shelter and specific requirements are generally promulgated by the Industrial Commissions of the States in which the shelters are to be used. If there are no applicable state standards, the requirements of the National Fire Prevention Association should be followed. In general, there should be two exits to preclude trapping the attendant in the event of fire. Other items to consider are steps, ladders, handrails around elevated work areas, and proper storage facilities for gas cylinders. Since gas cylinders must be fastened upright at all times, specific facilities must be provided for this purpose. The use of electrolytic hydrogen generation in lieu of compressed hydrogen in tanks is recommended.

A multipurpose dry chemical fire extinguisher (ammonium phosphate type) should be provided and located in an unobstructed area near an exterior door. Such an extinguisher can be used on Class A, B, and C fires; a 10-pound size should be sufficient. It is highly recommended that the extinguisher be one which is listed or labeled by a nationally recognized testing laboratory such as Underwriters' Laboratories.

2.3.4 Cost Estimates

Varying price conditions throughout the country and the instability of construction costs make it impossible to pinpoint the costs of a shelter. A fair estimate would be in the range of \$30 to \$40 per square foot. This estimate is based on providing facilities for toilet, heating, cooling, sink, and auxiliary elevated work platform. The cost of providing security fencing, automobile parking, and cabinetry has not been included.

Mobile facilities are the most costly, initially, and conventional construction would be the least costly. However, this is dependent on the labor situation.

Because of the high cost of these shelters, the use of public buildings should be considered. Where plumbing and electrical facilities are existent, necessary remodeling costs should run about $10 to $15 per square foot.

2.4 Sample Manifold Design

Continuous monitors contained within the station must be supplied with sample air which represents, in real time, the ambient atmosphere under investigation. To accomplish this requirement care must be exercised in the selection of the manifold system. Several variable parameters affecting the sampling manifold design are the diameter, length, flow rate, pressure drop, and materials of construction. A recent survey[3] of current practice in continuous air monitoring stations indicates that typical values of sampling intake line diameter, length, and flow rate were 1.2 cm, 7 meters, and 5 liters per minute, respectively. In most applications, these physical parameters would not be optimal and, therefore, are not recommended for use. The majority of these sampling lines were constructed of glass, stainless steel, or Teflon.

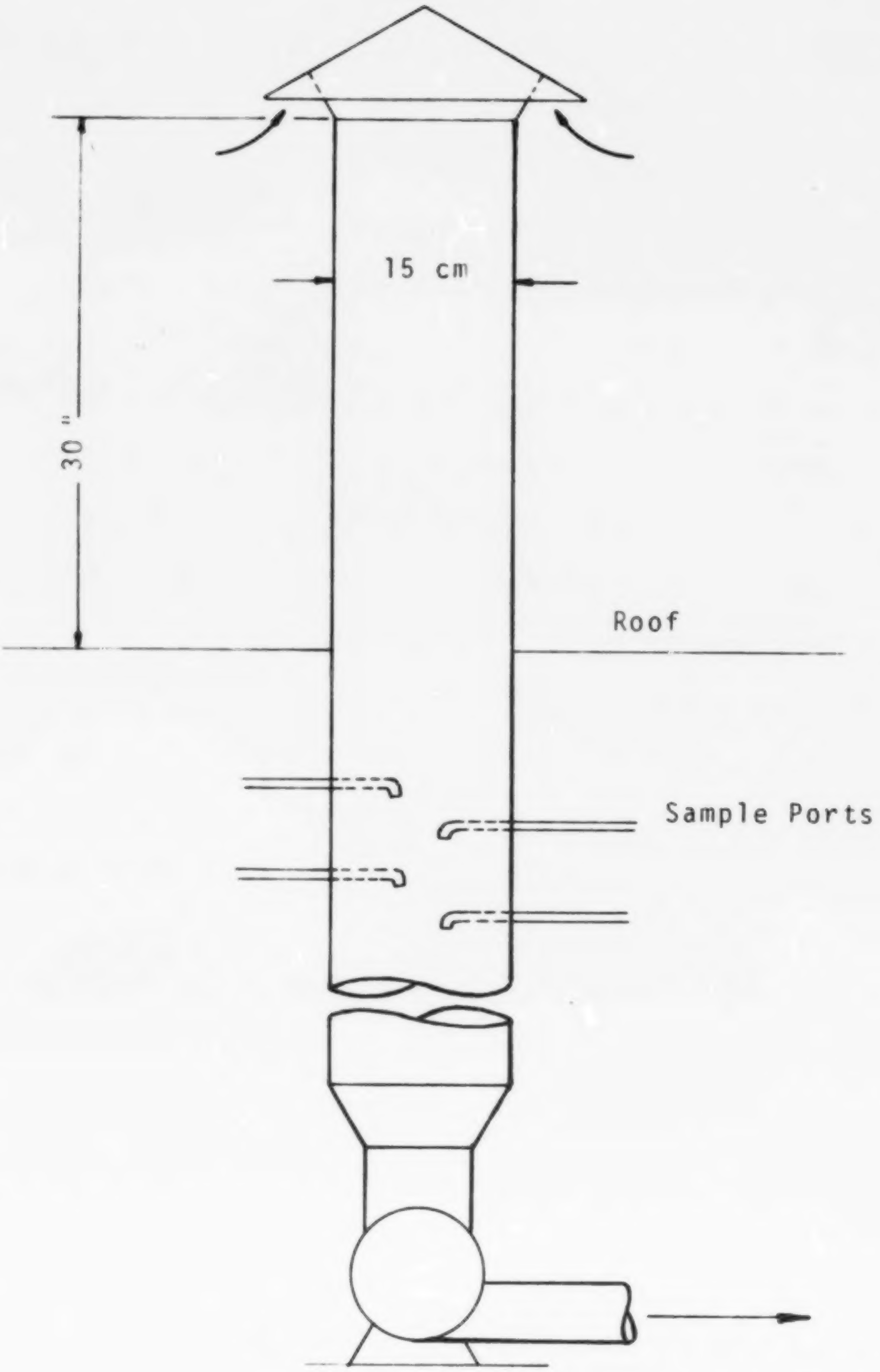
Losses within the sampling line can occur from reaction of the desired constituent with the manifold material and/or with deposited particulate materials on the walls of the manifold. Two system designs are used to minimize losses within the sample manifold; one is based on molecular diffusion theory and the other, a more conventional design, is based on utilization of nonreactive materials and good housekeeping practices.

2.4.1 Molecular Diffusion Design[5]

The transport of gases and small particles, in laminar flow down a vertical sampling inlet line with no bends, is by molecular diffusion. A reasonable assumption for a sampling probe of any material (even glass), if it is coated with a deposition of urban aerosol, is that the surface could act as a perfect absorber--i.e., the concentration is zero at the surface.

By the proper selection of a large diameter vertical inlet probe and maintaining a laminar flow throughout it, the sample air is not permitted to react with the walls of the probe. Removable sample lines constructed of Teflon or glass can be used to provide each instrument with sample air. These sample lines will require periodic cleaning or replacement. In fact it is good practice to clean sample lines before the initial use. A flow rate of 5 liters per minute in 1.5 cm diameter tubing (commonly used in monitoring stations) is not satisfactory for this application because of almost complete diffusion losses.

Diameters from 1.5 to 2.5 cm with 50 to 150 liters per minute are unacceptable because of high pressure drops. Therefore, inlet line diameters of 15 cm with a flow rate of 150 liters per minute are necessary if diffusion losses and pressure drops are to be minimized. This ensures that the inlet sampling probe collects and transports pollutants with minimal alteration from the condition and composition in which they existed in the atmosphere to the point of instrumental analysis. Such sampling ducts can be made of plastic, aluminum, or other similar materials. Figure 3 is an example of a molecular diffusion sampling manifold.


15 cm
30 "
Roof
Sample Ports

Blower - 150 l/min

Figure 3. Molecular diffusion sampling manifold.

In this system an inexpensive blower is required to maintain the air flow. Not only is such a configuration easier to construct than a glass system, but it also has the following advantages:

- A 15-cm pipe can be cleaned easily by pulling a cloth through it with a string.
- Sampling ports can be cut into the pipe at any location and, if unused, can be plugged with stoppers.
- Metal poses no breakage hazard.
- The pipe does not have to be clean to provide a representative sample, as in the case with smaller tubes.
- It is unnecessary to use a supposedly inert material by proper choice of size and flow rate.

2.4.2 Conventional Manifold Design

In practice it may be difficult to obtain the vertical laminar flow required for the molecular diffusion design because of the necessary elbows within the intake manifold system. Therefore, the conventional system is proposed which employs inert materials such as Pyrex glass and/or Teflon as the transport medium. The manifold should be designed in modular sections to enable frequent cleaning. (In relatively dirty urban areas, monthly cleaning is recommended.) The system[6] (see figure 4) consists of a vertical "candy cane" protruding through the roof of the shelter. The horizontal sampling manifold is connected by means of a tee to the vertical section. Connected to the other vertical outlet of the tee is a bottle which serves to collect heavy particles and moisture before they can enter the horizontal sections. A small blower (60 cfm at 0.0 inches of water static pressure) is placed at the exhaust end of the system. This will provide a flow through the system of approximately 3 to 5 cfm.

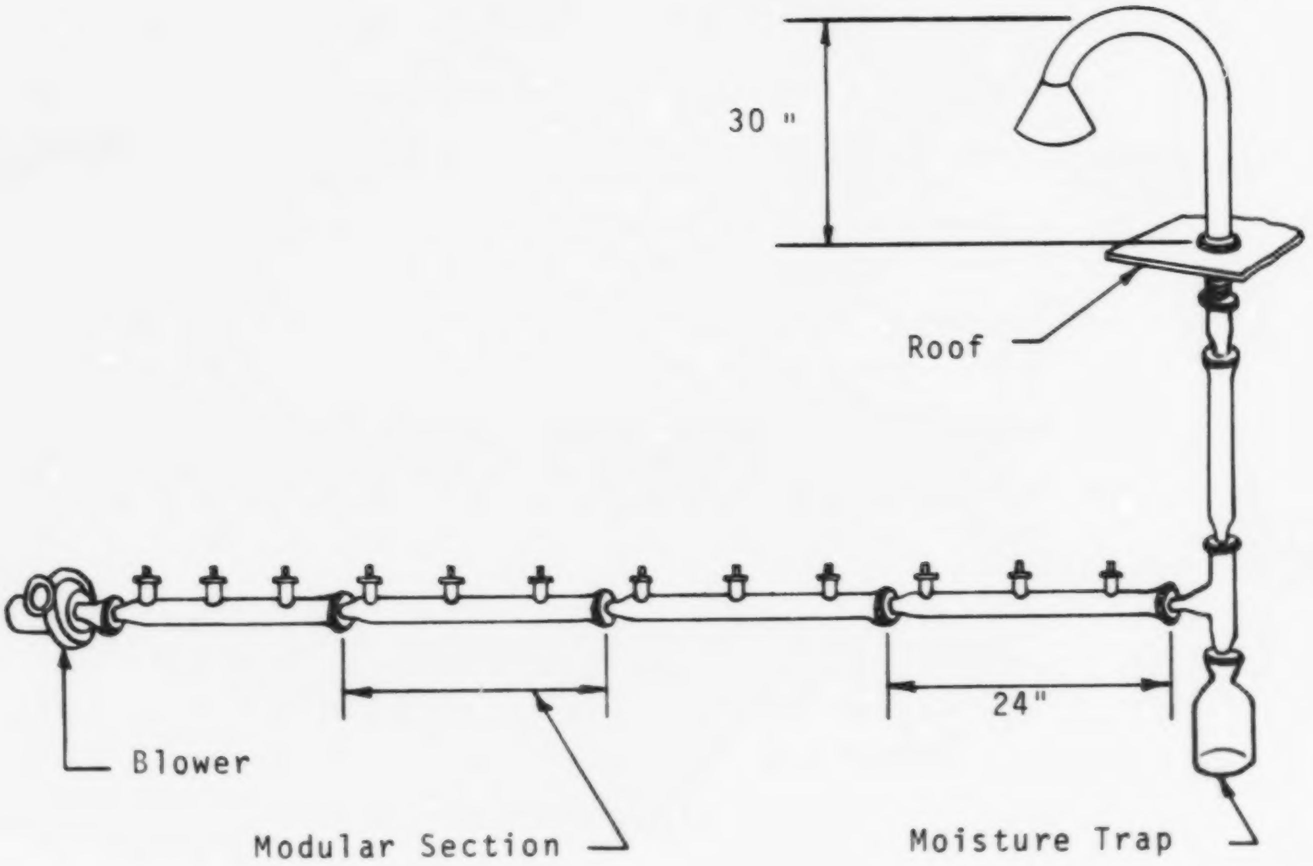


Figure 4. Conventional manifold system.

A high mass/velocity ratio within this system will reduce the sample residence time within the manifold and additionally will provide a minimum pressure drop therein. This can be achieved by employing large (50 mm or greater inside diameter) Pyrex glass tubing. The mass flow within the system should be approximately 3 to 5 times the total sample requirements of all the monitors connected to the system. Particulate monitoring instruments, such as paper tape samplers and nephelometers, should be provided with a separate intake probe. The probe should be so constructed that it is as short and as straight as possible to avoid particulate losses due to impaction on the walls of the probe.

Studies[7,8,9] have been conducted to determine the suitability of materials, such as polypropylene, polyethylene, PVC, Tygon, aluminum, brass, stainless steel, copper, Pyrex glass, and Teflon for use as intake sampling lines. Of the above materials, only Pyrex glass and Teflon are acceptable for use as intake sampling lines for all continuous monitoring equipment.

2.5 Remote Station Support Equipment

Equipment provisions for reagent preparation and instrument calibration should also be considered. The magnitude of this requirement will vary depending on the number of remote stations, their proximity to each other and to a central support laboratory. In all cases, equipment such as an analytical balance, colorimeter, calibration equipment, and a source of pure water (distilled or deionized) will be required to support the remote station. Much of this equipment could be maintained at a central support laboratory and used as needed in the field.

2.6 Selection of Monitors

Selection of continuous monitoring equipment should be made following a careful evaluation of published information pertaining to the instrumental specifications and a knowledge of the user's specific application. To aid the prospective user in making an objective comparison of instrumental specifications and performance characteristics, a comprehensive list of these factors has been developed.[10] For convenience, the factors are presented in Tables 5, 6, and 7. Table 5 covers descriptive factors needed to identify the instrument such as name of manufacturer, trade name, model number,

Table 5. DESCRIPTIVE FACTORS TO CONSIDER FOR THE COMPARISON OF AUTOMATIC AIR MONITORING EQUIPMENT

Instrument description	
Term or specification	Information required
Manufacturer and/or vendor(s)	Name and address of manufacturer or vendor(s) if manufacturer is to be unlisted.
Trade name and/or model no.	Trade name and/or model number applied by the manufacturer or the vendor.
Application	Purposes and use for which the instrument is designed (e.g.,: source or emission monitor, process control, chamber, ambient air monitor).
Measurement principle	Brief, concise, simple explanation of the principle upon which the measurement is based; also includes information such as wavelength, detection principle, reagent(s), etc.
Schematic diagram	A simple diagram of the basic flow and, where applicable, electronic circuits.
Auxiliary equipment	A listing of the peripheral items needed to make the instrument operational; may include display units, amplifiers, pumps, pressurized cylinders of gases, reagents, etc., which are not a part of or contained within the analyzer cabinet. (See definition, section 6.0.)

Table 6. INSTALLATION AND OPERATIONAL FACTORS TO CONSIDER FOR THE COMPARISON OF AUTOMATIC AIR MONITORING EQUIPMENT

Installation and operation	
Term or specification	Information required
Space requirements	(See definition, section 6.1)
Weight	(See definition, section 6.1)
Power requirements	Electrical power needed--voltage(s), AC and/or DC, frequency, wattage, or current.
Temperature operating range	(See definition, section 6.3)
Humidity operating range	(See definition, section 6.3)
Vibration operating range	(See definition, section 6.3)
Portability	Specify if unit is designed or may be adapted for portable or mobile operation.
Signal output	The signal output from the analyzer or detector. Specify form of signal voltage(s), current, power, and whether output is linear or nonlinear. If nonlinear, specify whether exponential or other unspecified function.
Air sampling rate	Rate of sample air flow in volume per unit time, usually millimeters per minute or liters per minute.
Sample line pressure	The range of pressure within the sample line, usually negative, over which the instrument will need performance specifications.

Table 6 (continued). INSTALLATION AND OPERATIONAL FACTORS TO CONSIDER FOR THE COMPARISON OF AUTOMATIC AIR MONITORING EQUIPMENT

Term or specification	Information required
Sample line construction	Internal diameter, length, and material of air sample line through which the sample may pass and meet instrument performance specifications.
Reagent flow rate	Flow rate of all critical chemical reagents in volume per unit time, usually milliliters per minute.
Reagent consumption (weekly)	Volume of reagent consumed by the analyzer per unit time, usually in milliliters or in liters per week.
Calibration	Frequency and type of calibration needed for the instrument to maintain performance specifications. Calibrations may be performed statically with resistors, screens, optical filters, electrical signals, standard calibrating solutions, or dynamically with a gas of known concentration.

Table 7. PERFORMANCE FACTORS TO CONSIDER FOR THE COMPARISON OF AUTOMATIC AIR MONITORING EQUIPMENT

Performance characteristics	
Term of specification	Information required
Accuracy	(See definition, section 6.3)
Minimum detectable sensitivity	(See definition, section 6.3)
Minimum detectable change	(See definition, section 6.3)
Precision	(See definition, section 6.3)
Reproducibility	(See definition, section 6.3)
Linearity	(See definition, section 6.3)
Zero drift	(See definition, section 6.3)
Span drift	(See definition, section 6.3)
Noise	(See definition, section 6.3)
Range(s)	(See definition, section 6.3)
Initial response time	(See definition, section 6.3)
Rise time	(See definition, section 6.3)
Time to 95% response	(See definition, section 6.3)
Fall time	(See definition, section 6.3)
Response time constant	(See definition, section 6.3)
Warmup time	(See definition, section 6.3)
Interference(s)	(See definition, section 6.3)
Interference equivalent	(See definition, section 6.3)

the measurement principle used, etc. Table 6 covers factors which govern the installational and operational requirements such as size, space, weight, power, temperature and humidity ranges, audible instrument noise, air sampling rate, and maintenance needs (including calibration method and frequency). Table 7 covers performance factors or the fidelity of instrument output in response to dynamic changes in pollutant concentration. Opposite each term in Tables 5, 6, and 7 is an explanation of the information to be obtained. In some cases the terms are defined in Section 6.3, Performance Characteristics.

2.6.1 Suggested Performance Specification for Automatic Monitors

Several performance specifications which should be considered in selecting equipment are presented in Table 8. All of the specifications may not be required in all monitoring situations and the user will have to use his best judgment in selecting specifications important to him. The specifications of Table 8 are realistic and instruments are currently available which can meet all of the specifications given. For monitoring to determine compliance with air quality standards, the user must be especially careful that the instruments measure with sufficient sensitivity, specificity, precision, and lack of drift.

2.6.2 Recommended Monitoring Methods

The Environmental Protection Agency[11] has published reference methods for the measurement of sulfur dioxide, nitrogen dioxide, carbon monoxide, photochemical oxidants, and suspended particulates. Table 9 is a summary of these methods.

Table 8. SUGGESTED PERFORMANCE SPECIFICATIONS FOR AUTOMATIC MONITORS

Specification	Pollutants				
	Sulfur dioxide	Carbon monoxide	Photochemical oxidant*	Nitrogen dioxide	Hydrocarbons (CH_4)
Range	0-2620μg/m^3 (0-1 ppm)	0-58 mg/m^3 (0-50 ppm)	0-880 μg/m^3 (0-0.5 ppm)	0-1880 μg/m^3 (0-1 ppm)	0-16 mg/m^3 (0-25 ppm)
Minimum detectable sensitivity	26 μg/m^3 (0.01 ppm)	0.6 mg/m^3 (0.5 ppm)	20 μg/m^3 (0.01 ppm)	19 μg/m^3 (0.1 ppm)	0.16 mg/m^3 (0.25 ppm)
Rise time, 90%	5 min.	5 min.	5 min.	5 min.	5 min.
Fall time, 90%	5 min.	5 min.	5 min.	5 min.	5 min.
Zero drift	± 1% per day and ± 2% per 3 days	± 1% per day and ± 2% per 3 days	± 1% per day and ± 2% per 3 days	± 1% per day and ± 2% per 3 days	± 1% per day and ± 2% per 3 days
Span drift	± 1% per day and ± 2% per 3 days	± 1% per day and ± 2% per 3 days	± 1% per day and ± 2% per 3 days	± 1% per day and ± 2% per 3 days	± 1% per day and ± 2% per 3 days
Precision	± 2%	± 4%	± 4%	± 4%	± 4%
Operation period	3 days	3 days	3 days	3 days	3 days
Noise	± 0.5% (full scale)	± 0.5% (full scale)	± 0.5% (full scale)	± 0.5% (full scale)	± 0.5% (full scale)
Interference equivalent	26 μg/m^3 (0.01 ppm)	1.1 mg/m^3 (1 ppm)	20 μg/m^3 (0.01 ppm)	19 μg/m^3 (0.01 ppm)	.32 mg/m^3 (0.5 ppm)
Operating temperature fluctuation	± 5° C	± 5° C	± 5° C	± 5° C	± 5° C
Linearity	2% (full scale)	2% (full scale)	2% (full scale)	2% (full scale)	2% (full scale)

*Corrected for NO_2 & SO_2

Table 9. RECOMMENDED METHODS FOR AIR QUALITY SURVEILLANCE

Pollutant	Recommended method
Suspended particulates	High volume sampler
Sulfur dioxide	Pararosaniline
Carbon monoxide	Nondispersive IR
Nitrogen dioxide	Jacobs-Hochheiser
Oxidants	Gas phase chemiluminescence olefin ozone reaction

2.6.3 Principles of Measurement

As a prerequisite for making this objective evaluation, a general knowledge of the measurement technique employed by the various specific monitors is essential. The following operational principles are commonly incorporated in continuous air monitoring instrumentation.

2.6.3.1 Conductivity. The principle for conductometry, that is, electric conductance by soluble electrolytes, has had wide application as an analytical procedure. The conductance of electrolytes in solution is proportional to the number of ions present and their mobilities. In dilute sample solutions, the measured conductivity can be directly related to the concentration of ionizable substance present. Sulfur dioxide has been measured by this procedure in continuous recording instrumentation for more than 25 years. The basic concept involves absorption of sulfur dioxide in deionized water (or a very dilute reagent) to produce an acid having conductance sufficient to be detected by a conductivity cell. Monitors employing de-ionized water as the reagent result in the formation of sulfurous acid (H_2SO_3). Interferences from carbon dioxide, salt aerosols, acid mists, and basic gases are common. Most sulfur dioxide analyzers use distilled or de-ionized water reagent modified by the addition of hydrogen peroxide and a small amount of sulfuric acid. This modified reagent forms sulfuric acid (H_2SO_4) upon reaction with sulfur dioxide. THe acidic property of this modified reagent reduces the solubility of carbon dioxide gas within the reagent and minimizes this interference. However, this method is still subject to gross interferences and is not recommended. Figure 5 is a schematic diagram of a typical conductivity type monitor.

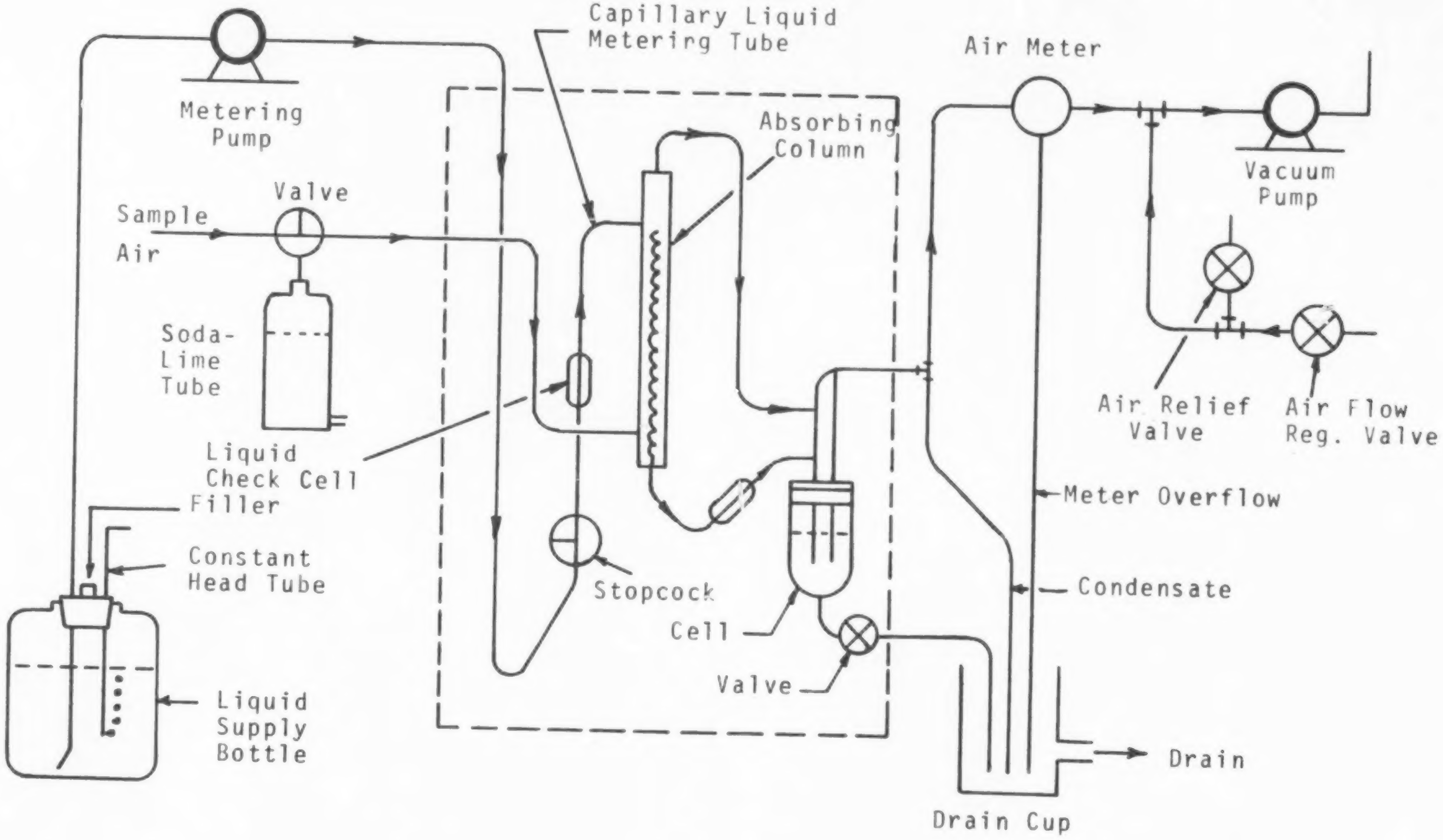
2.6.3.2 Colorimetry. Colorimetry can be defined as a mode of analysis in which the quantity of a colored substance is determined by measuring the relative amount of light passing through a solution of that substance. The constituent may itself be colored and thus be determined directly, or it can be reacted with a reagent to form a colored compound and thus be determined indirectly.

The physical law that underlies colorimetric analysis is commonly referred to as the Beers law.[12] It states that the degree of light absorption by a colored solution is a function of the concentration and the length of the light path through the solution.

These principles are commonly employed for the continuous measurement of three air pollutants; sulfur dioxide, nitrogen dioxide, and oxidants.

Figure 6 is a schematic diagram of a typical colorimetric type monitor. As shown, an atmospheric sample is drawn into the air-reagent flow system, first entering the absorber or scrubber where the desired constituent is reacted with the appropriate reagent. The air sample is separated from the reacted reagent and passed through the air pump

Figure 5. Schematic diagram of a typical SO_2 conductivity monitor.


Metering Pump
Capillary Liquid Metering Tube
Air Meter
Absorbing Column
Vacuum Pump
Valve
Sample Air
Soda-Lime Tube
Air Relief Valve
Air Flow Reg. Valve
Liquid Check Cell Filler
Meter Overflow
Constant Head Tube
Stopcock
Condensate
Cell
Valve
Liquid Supply Bottle
Drain
Drain Cup

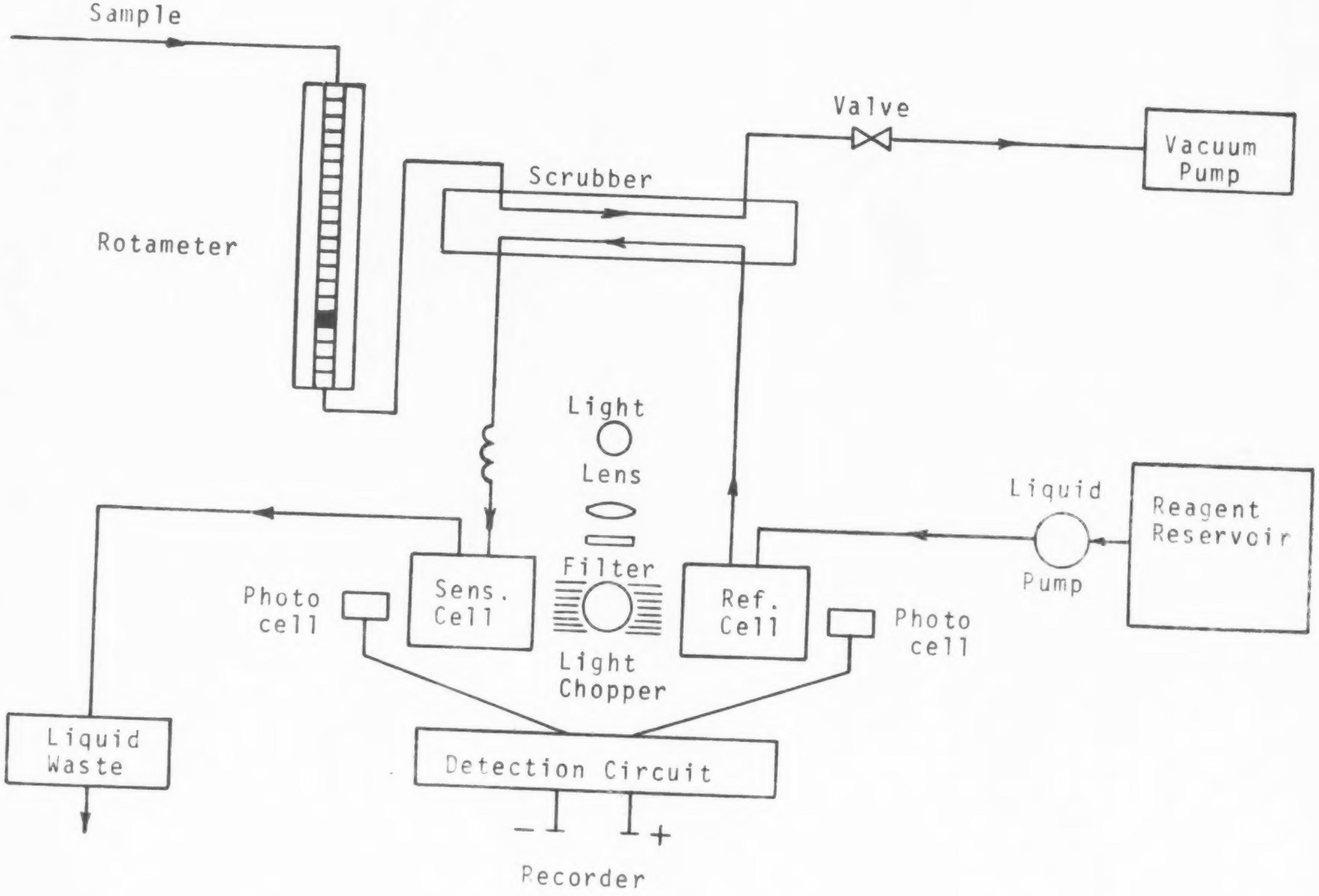

Sample
Rotameter
Scrubber
Valve
Vacuum Pump
Light
Lens
Filter
Light Chopper
Liquid
Pump
Reagent Reservoir
Photo cell
Sens. Cell
Ref. Cell
Photo cell
Liquid Waste
Detection Circuit
−
+
Recorder

Figure 6. Schematic diagram of a typical colorimetric monitor.

and finally discharged to the atmosphere. The reacted reagent passes from the bottom of the absorber into the continuous flow colorimeter where the absorbance of the solution is measured. In most cases a dual flow colorimeter, as shown, is employed whereby the absorbance of the unreacted reagent is initially measured.

2.6.3.3 Coulometry. Coulometry is a mode of analysis wherein the quantity of electrons required to oxidize or reduce a desired substance is measured. This measured quantity, expressed as coulombs, is proportional to the mass of the reacted material according to Faraday's law. Coulometric titration cells for the continuous measurement of sulfur dioxide, oxidants, and nitrogen dioxide have been developed using this principle. Figure 7 is a typical flow diagram of a coulometric type monitor.

One class of cells generally employed in continuous air monitoring is designed to respond to materials which are oxidized or reduced by halogens and/or halides. Upon introduction of a reactive material, the halogen-halide equilibrium is shifted. The system is returned to equilibrium by means of a third electrode which regenerates the depleted species. The current required for this generation is measured and is directly proportional to the concentration of the depleted species, which in turn is proportional to the quantity of desired constituent. This mode of analysis can be classified as secondary coulometry, usually employing a dynamic iodimetric or bromimetric titration. These systems are designed to respond with a sensitivity in the lower parts-per-billion range. Most commercial coulometric systems are made specific by the use of prefiltration devices,

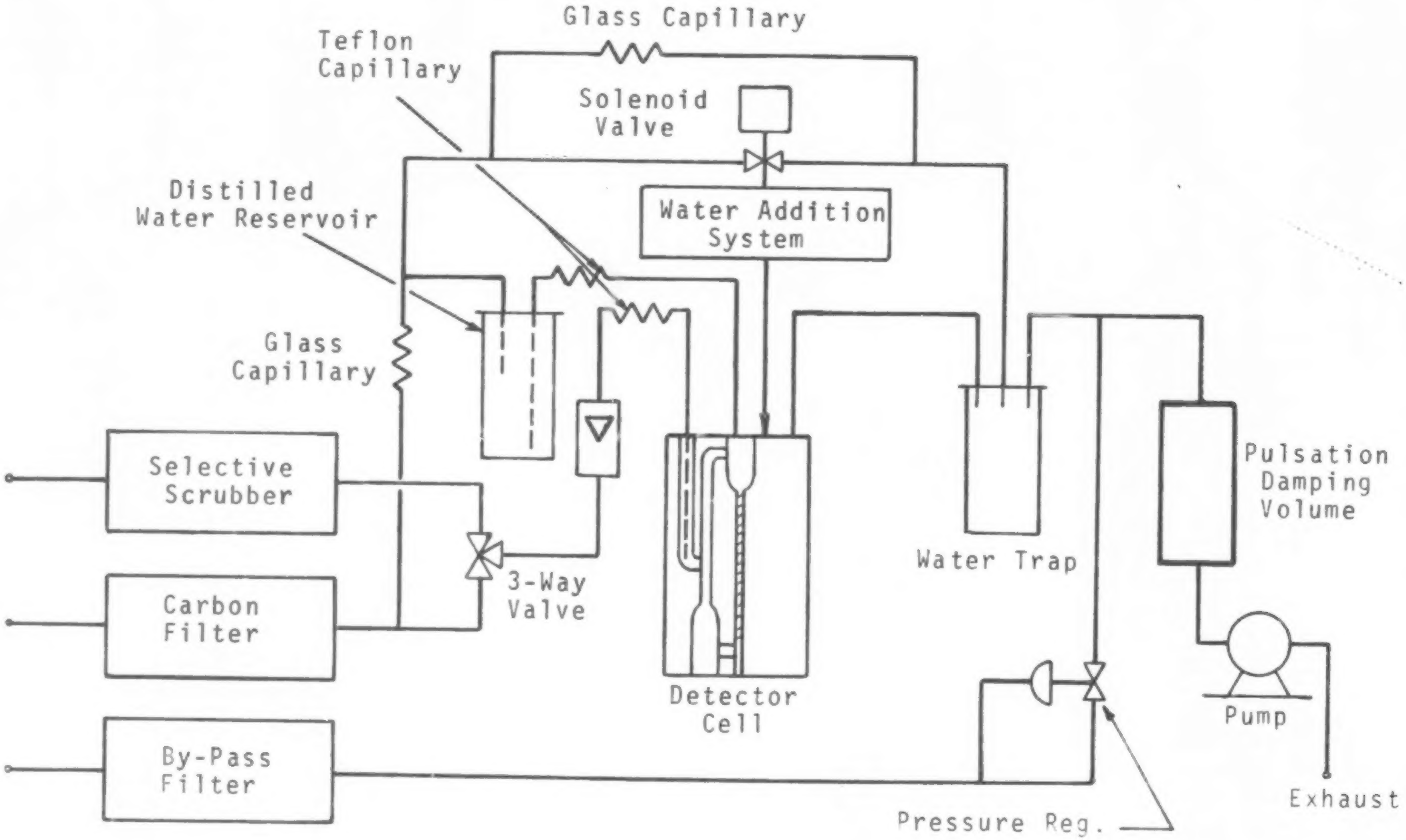

Glass Capillary
Teflon Capillary
Solenoid Valve
Distilled Water Reservoir
Water Addition System
Glass Capillary
Selective Scrubber
Carbon Filter
By-Pass Filter
3-Way Valve
Detector Cell
Water Trap
Pulsation Damping Volume
Pump
Exhaust
Pressure Reg.

Figure 7. Schematic diagram of a typical coulometric monitor.

scrubbers, and/or chromatographic techniques that retain interfering compounds and permit passage of the desired constituents. Some loss of pollutants may occur in these devices, probably not exceeding 10 percent.

Another type of coulometric cell, designed for oxidant analysis, employs amperometry. The oxidant reacts with an iodide solution within the cell releasing iodine which depolarizes the cathode, thus permitting current flow which is proportional to the oxidant concentration. By passing reagent and sample over the electrodes, a continuous measurement is achieved. This type of monitor is also subject to interferences. Materials which undergo oxidation will appear as negative interferences; those that undergo reduction will appear as positive interferences. Figure 8 is a diagram of a typical amperometric-type monitor.

2.6.3.4 Flame Photometry. Flame photometry is based on the measurement of the intensity of specific spectral lines resulting from quantum excitation and decay of elements by the heat of a flame. Volatile compounds are introduced into the flame by mixing them with the flammable gas or with the air supporting the flame. Nonvolatile compounds are aspirated from a solution into the flame. The specific wave length of interest can be isolated by means of narrow-band optical filters, diffraction gratings, or by means of a prism. The intensity of the specific wavelength can be measured by means of a phototube or photo-multiplier tube and associated electronics.

Recent development of flame photometric detectors[13,14] having a semispecific response to volatile phosphorus and sulfur compounds has led to their use in continuous monitoring of gaseous sulfur compounds. This flame photometric detector consists of a photo-mutiplier tube

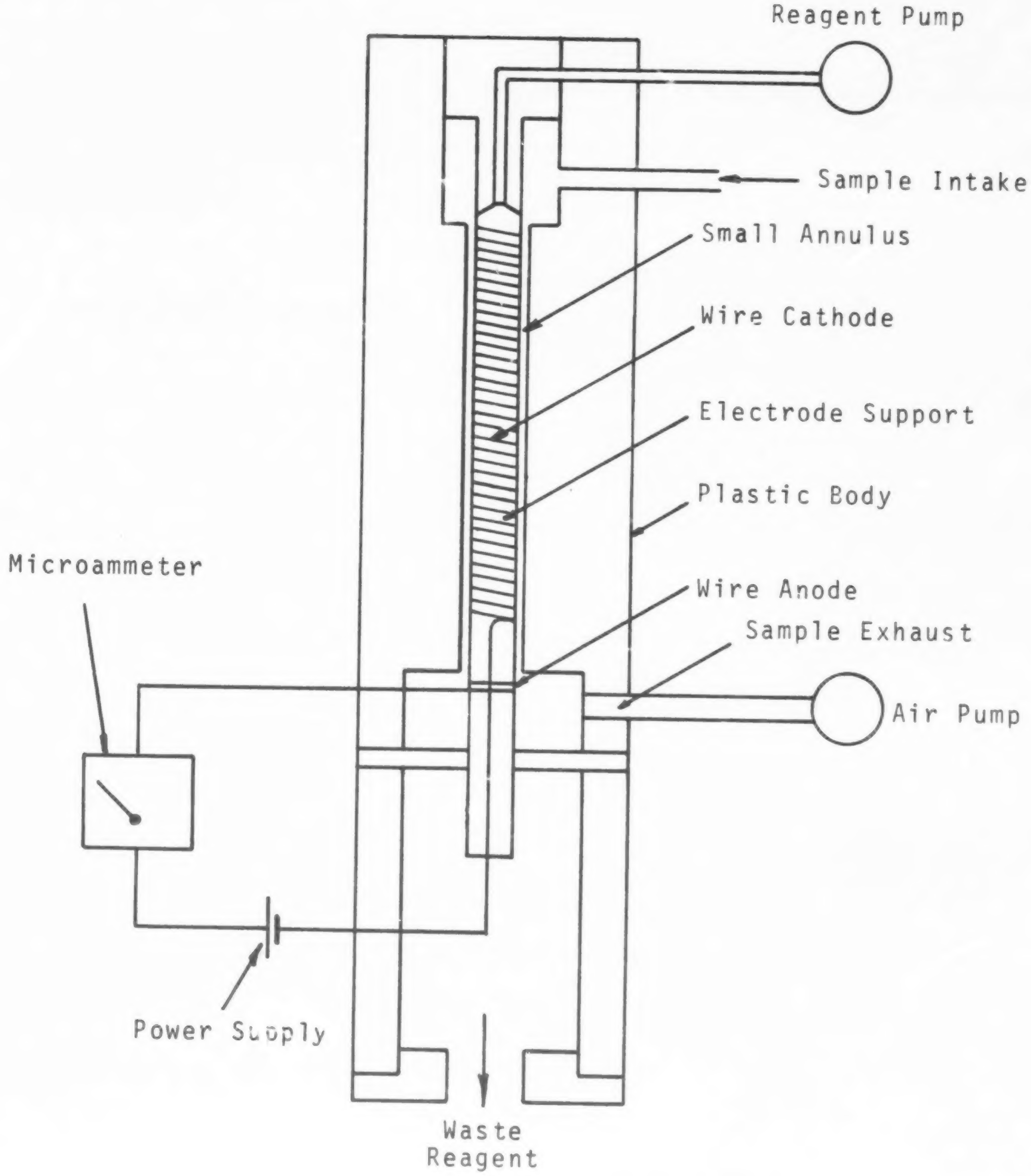

Reagent Pump
Sample Intake
Small Annulus
Wire Cathode
Electrode Support
Plastic Body
Microammeter
Wire Anode
Sample Exhaust
Air Pump
Power Supply
Waste Reagent

Figure 8. Schematic diagram of a typical amperometric monitor.

viewing a region above the flame through narrow-band optical filters. When sulfur compounds are introduced into the hydrogen-rich flame, they produce strong luminescence between 300 and 423 nanometers. A specificity ratio for sulfur to nonsulfur compounds of approximately 20,000 to 1 is achieved with a narrow-band optical filter in the range between 5 ppb and about 900 ppb. Other sulfur compounds result in positive interferences while monitoring for SO_2, since the detector responds to all sulfur compounds. Discretion should be used in interpreting data obtained from this detector when it is located in areas where other sulfur compounds exist. For example, H_2S and CH_3SH are found in conjunction with SO_2 in the vicinity of kraft paper mills and CS_2 and H_2S in the vicinity of oil fields and refineries. Figure 9 is a schematic diagram of a typical flame photometric sulfur monitor.

Separation of parts-per-billion levels of SO_2, H_2S, CS_2, and CH_3SH has recently become feasible through the use of chromatographic techniques.[15] This mode of separation followed by flame photometric detection of the separated sulfur compounds has led to the development of a new type of semicontinuous monitor for sulfur containing gases which is specific and free from interferences.

2.6.3.5 Flame Ionization. Instruments employing flame ionization detectors, originally designed for gas chromatographic detection of organic compounds, have had wide application as a continuous monitor for hydrocarbons. The sample to be analyzed is mixed with a hydrogen fuel and passed through a small jet; air supplied to the annular space around the jet supports combustion. Carbon-containing compounds carried into the flame result in the formation of ions. An electrical potential

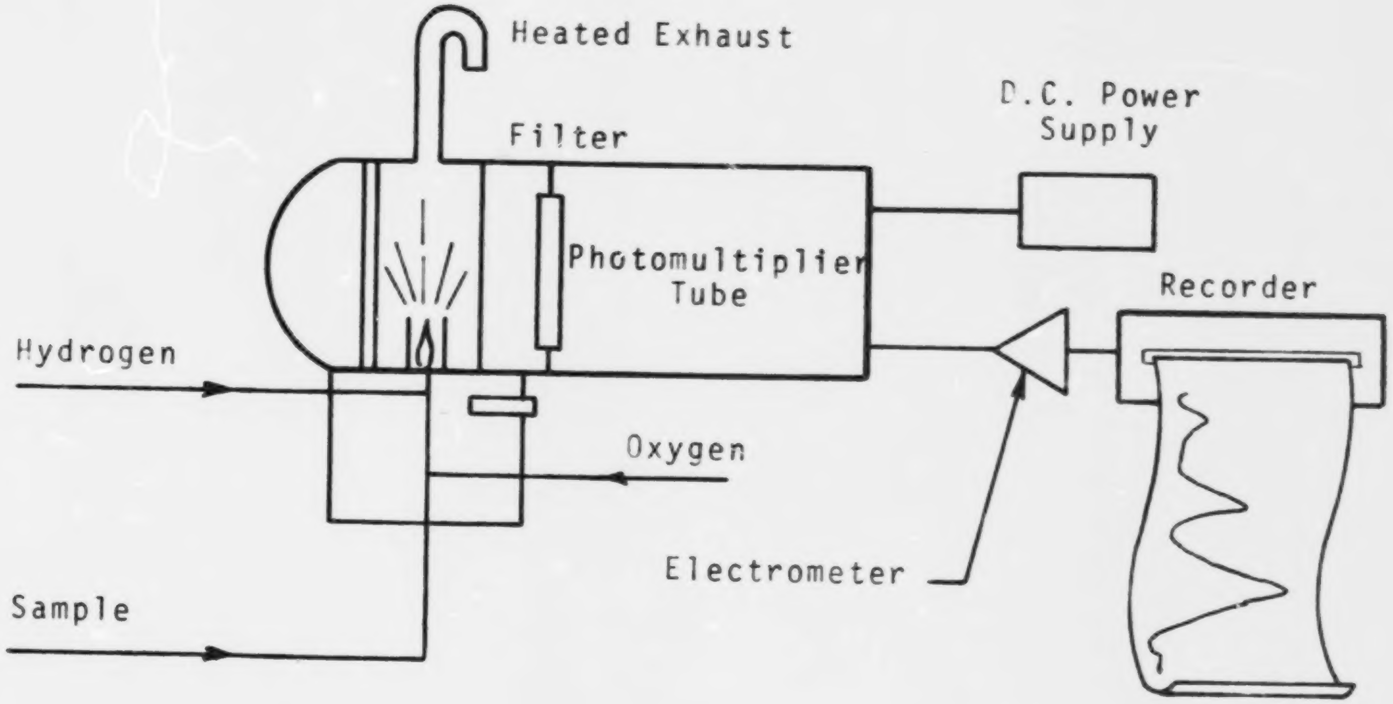

Heated Exhaust
Filter
D.C. Power Supply
Photomultiplier Tube
Recorder
Hydrogen
Oxygen
Electrometer
Sample

Figure 9. Schematic diagram of a typical flame photometric sulfur monitor.

across the flame jet and an ion collector electrode produces an ion current proportional to the number of carbon atoms in the sample.

Advantages inherent in this detector are that it is free from interferences from inorganic gases, has a rapid response time, and has a low "noise background" level. Figure 10 is a schematic diagram of a typical hydrogen flame ionization type monitor.

Recent investigations involving automated gas chromatographic[16] separation of the air sample into three fractions has led to the development of semicontinuous monitor for CO, CH_4, and total hydrocarbons. Measured volumes of ambient air are delivered periodically (4 to 12 times per hour) to a hydrogen flame ionization detector to measure its total hydrocarbon (THC) content. An aliquot of the same air sample is introduced into a stripper column which removes water, carbon dioxide, and hydrocarbons other than methane. Methane and carbon monoxide are passed gravitatively to a gas chromatographic column where they are separated. The methane is eluted first and is passed unchanged through a catalytic reduction tube into the slave ionization detector. The carbon monoxide is eluted into the catalytic reduction tube where it is reduced to methane before passing through the flame ionization detector. Between analyses the stripper column is backflushed to prepare it for subsequent analysis. Hydrocarbon concentrations corrected for methane are determined by subtracting the methane value from the total hydrocarbon value.

2.6.3.6 Nondispersive Infrared Photometry. The infrared absorption characteristics of several gases and vapors make possible their detection and analysis in continuous analyzers. Carbon monoxide as an air contaminant is uniquely suited to this method of analysis,

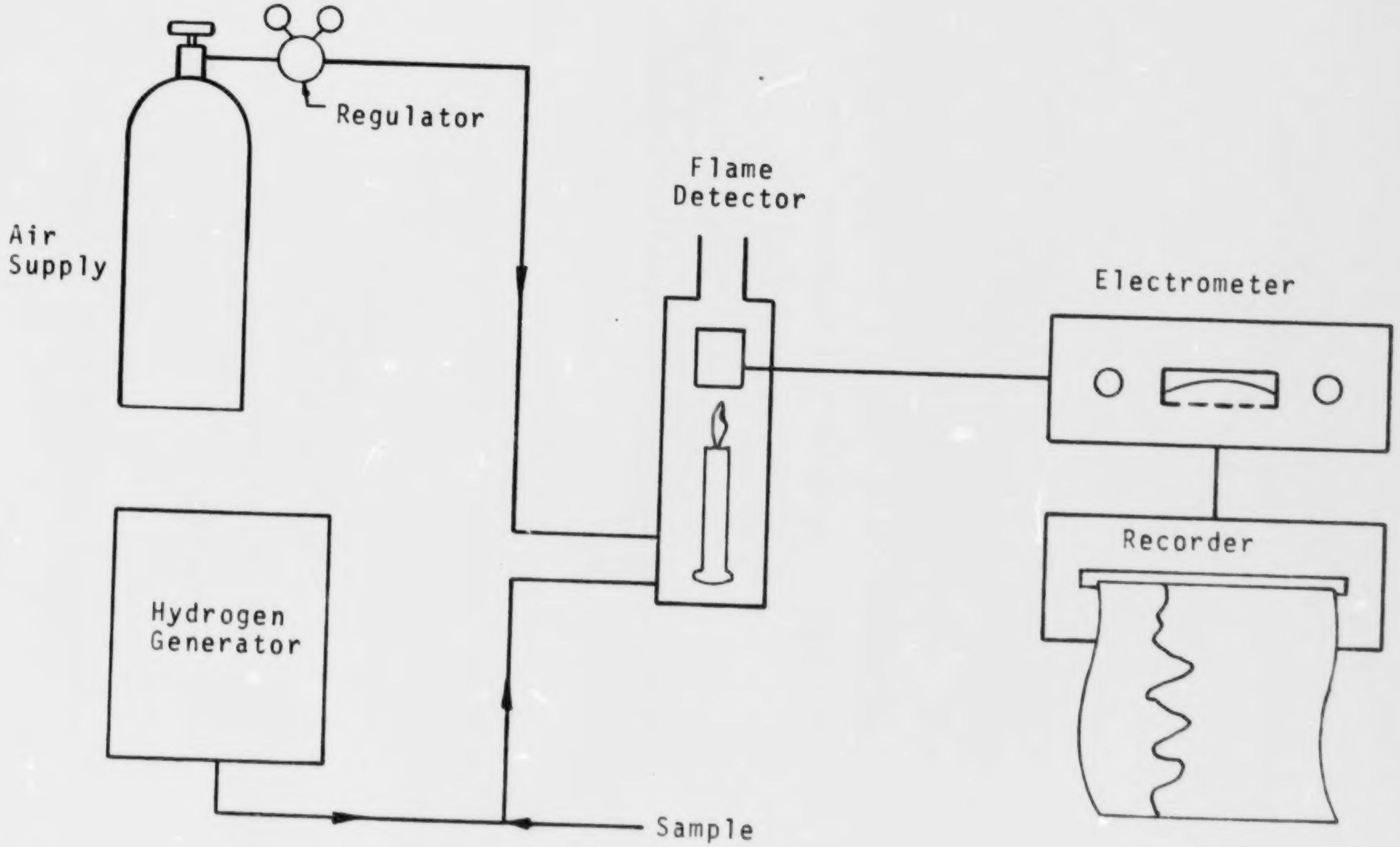

Air
Supply
Regulator
Flame
Detector
Electrometer
Recorder
Hydrogen
Generator
Sample

Figure 10. Schematic diagram of a typical flame ionization monitor.

as its absorption characteristics and typical concentrations make possible direct sampling.

A typical analyzer (Figure 11) consists of a sampling system, two infrared sources, sample and reference gas cells, detector, control unit and amplifier, and recorder. The reference cell contains a noninfrared-absorbing gas while the sample cell is continuously flushed with the sample atmosphere. The detector consists of a two-compartment gas cell (both filled with carbon monoxide under pressure) separated by a diaphragm whose movement causes a change of electrical capacitance in an external circuit, and ultimately an amplified electrical signal which is suitable for input to a servo-type recorder.

During analyzer operation an optical chopper intermittently exposes the reference and sample cells to the infrared sources. At the frequency imposed by the chopper, a constant amount of infrared energy passes through the reference cell to one compartment of the detector cell while a varying amount of infrared energy, inversely proportional to the carbon monoxide concentration in the sample cell, reaches the other detector cell compartment. These unequal amounts of residual infrared energy reaching the two compartments of the detector cell cause unequal expansion of the detector gas. This unequal expansion causes variation in the detector cell diaphragm movement resulting in the electrical signal described earlier.

The output of this instrument is independent of sample flow rate. A reduction in the resolution of rapid changes in concentration can be made by introducing additional volume in the sample line ahead of the analyzer unit.

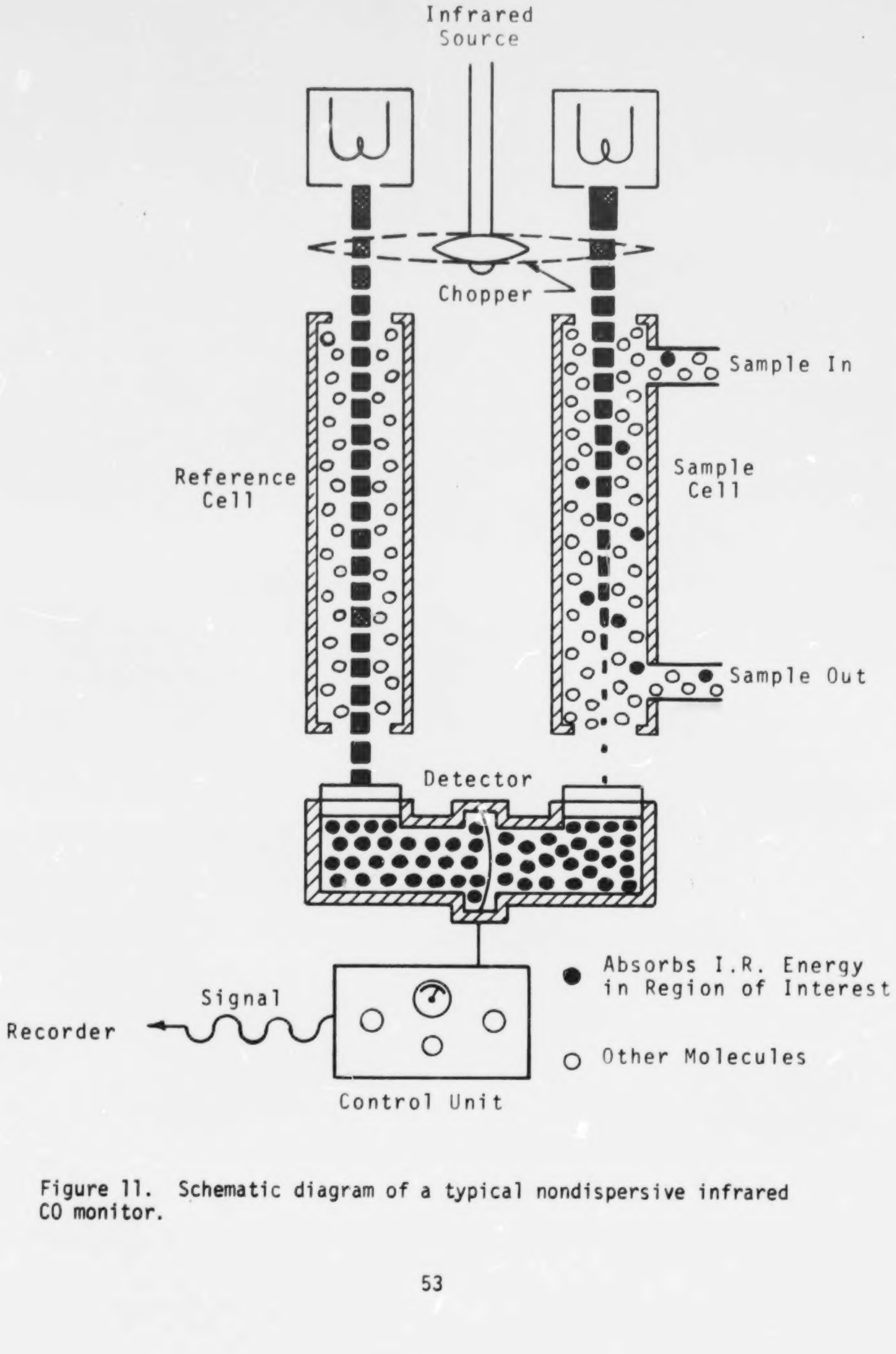

Infrared Source
Chopper
Reference Cell
Sample In
Sample Cell
Sample Out
Detector
● Absorbs I.R. Energy in Region of Interest
Signal
Recorder
○ Other Molecules
Control Unit

Figure 11. Schematic diagram of a typical nondispersive infrared CO monitor.

2.6.3.7 Reflectance and Transmittance. Soiling. The tape sampler is used to measure suspended particulates in ambient air. Air is drawn through a section of white filter paper. The most generally accepted sampling parameters for this measurement are: a 1-inch diameter spot, 7.07 ℓ/min (0.25 cu ft/min) flow rate and a two-hour sampling period. At the end of the sampling period, the tape advances automatically by means of a timing mechanism, placing a clean section of filter tape at the sampling port. The collected spot is automatically positioned under a photoelectric reflectance or transmittance head which evaluates the density of the spot by measuring the light reflected from or transmitted through the spot to the cell. In general the greater the amount of particulate matter filtered out of the air, the darker the spot and the smaller the amount of light reflected or transmitted. The quantity of air sampled is expressed as linear feet and the final result reported in either of two units of measurement, the COH or the RUDS, per 1000 linear feet of air. The units of 1000 linear feet can be determined as follows:

$$\text{LF (units of 1000)} = \frac{Q \times t}{1000 \times A} \quad ,$$

where LF is linear feet,

Q is sample air flow rate in cubic feet per minute,

t is sampling time, minutes,

A is cross-sectional area of filter spot, square feet.

The COH[17] unit (coefficient of haze) can be defined as that quantity of particulate matter which produces an optical density of

0.01 when measured by light transmittance in the region of 375 to 450 nanometers. The transmittance of a clean filter is used as a reference and is set at 0.0 density (or 100% transmittance). The light transmitted through the filter tape is expressed as follows:

$$\text{Optical density} = \log \frac{I_o}{I} ,$$

where I_o is the initial intensity of transmitted light through clean filter paper,

I is the transmittance observed through the soiled filter paper.

The RUDS[18] (reflectance unit of dirt shade) can be defined as that quantity of particulate matter which produces an optical reflectance of 0.01 when measured by reflectance through a green filter. The reflectance of a clean filter paper is set at 100% on the reflectance meter and is used as a reference. The reflectance of light from the filter tape is expressed as follows:

$$\text{Optical Reflectance} = \log \frac{R_o}{R}$$

where R_o is the initial intensity of reflected light from "clean" filter tape

R is the reflectance observed from the soiled filter tape.

This RUDS unit is also expressed in terms of 1000 linear feet of sample collected. There is no general conversion factor which can be used between the COH and RUDS units: these measurements are dependent upon varying parameters such as the color of the particulates collected, their size distribution, depth of penetration in the filter tape, and the variation of paper tape thickness. There also is a general lack of uniform correlation between tape sampler measurements and high volume measurements. Figure 12 is a diagram of a typical tape sampler.

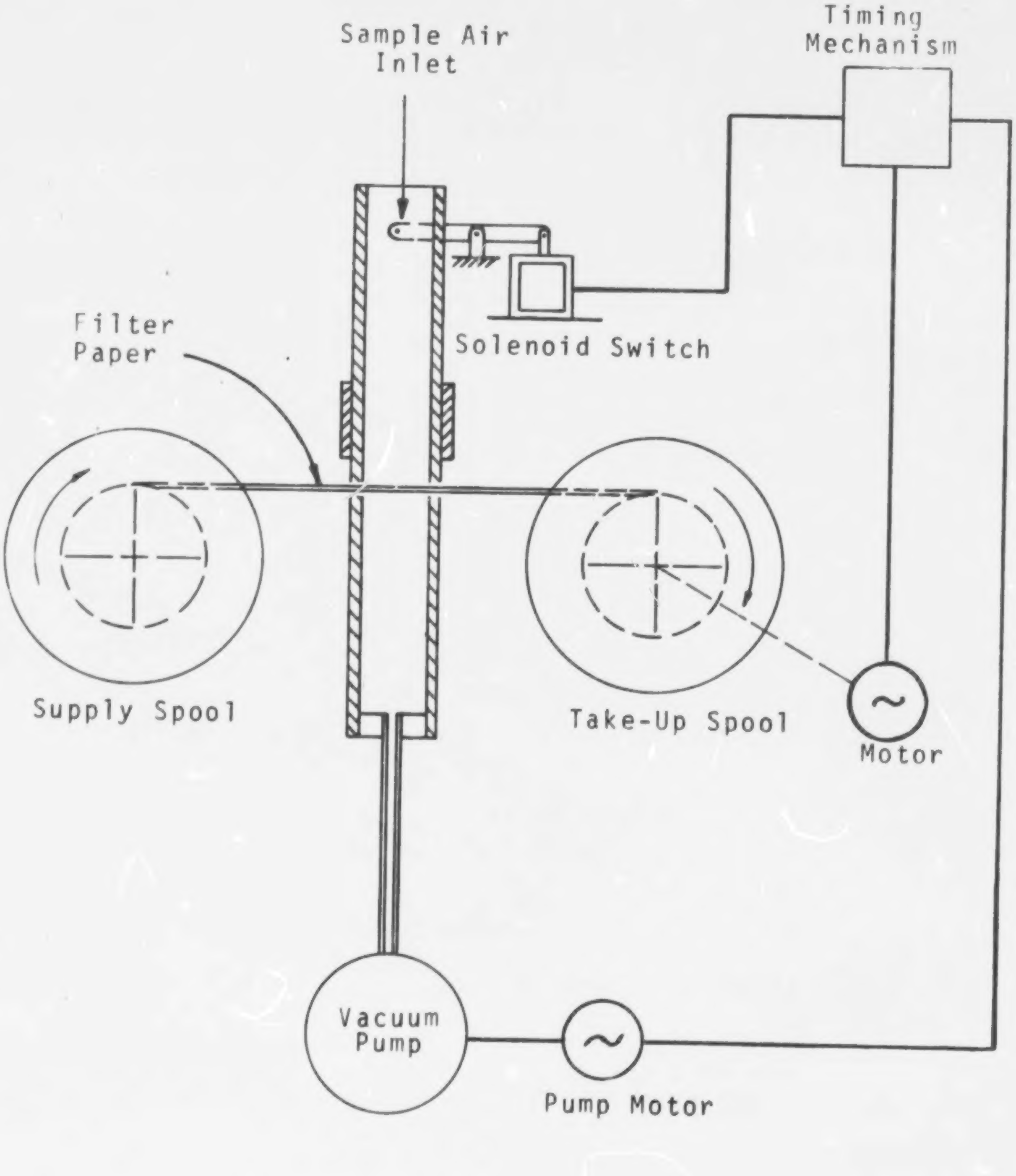

Sample Air Inlet
Timing Mechanism
Filter Paper
Solenoid Switch
Supply Spool
Take-Up Spool
Motor
Vacuum Pump
Pump Motor

Figure 12. Schematic diagram of a typical tape sampler.

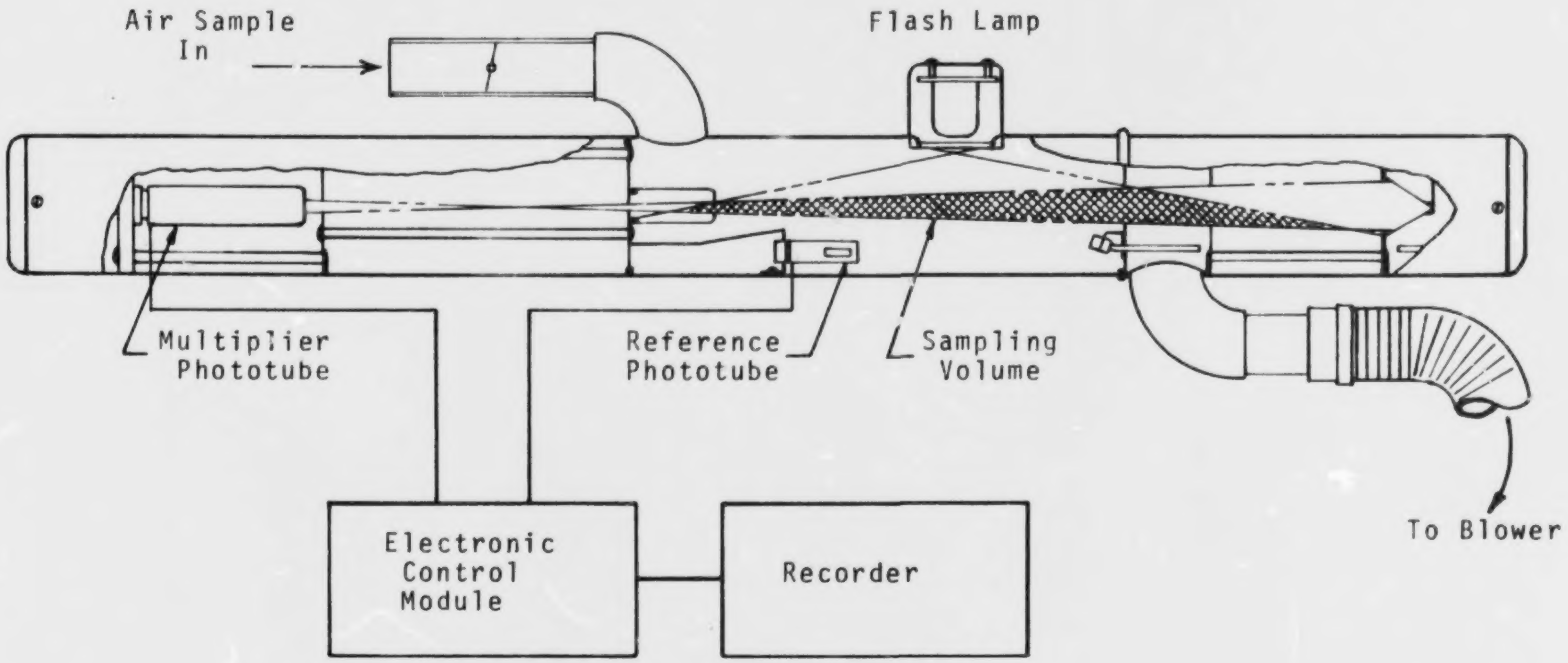
2.6.3.8 Nephelometry. A common effect of particulate air pollution is the reduction of visibility. Small particles suspended in the air scatter light out of the line of vision, making distant objects appear less distinct. Visual range can be defined as that distance at which the difference in contrast between the background and the object being observed is too small to perceive.

The air sample is drawn into the detection chamber where it is illuminated by a pulsed-flash lamp. The scattered light is measured over a range of scattering angles of 9° to 170° by means of a photomultiplier tube[19] (See Figure 13). The signal produced by the photomultiplier tube is averaged and compared with a reference voltage from another phototube illuminated by the flash lamp. Calibration is performed by introducing clean filtered air and Freon 12 as reference sources. The amount of light scattering is proportional to the mass concentration ($\mu g/m^3$) of suspended particulates if the mass and size distribution of the particles is assumed constant, a good assumption owing to the inherent size-limitation constraints for well-mixed, aged aerosols.

Measurements of suspended particulates with this device afford the user a continuous measurement in contrast with high volume sampling and weighing techniques which are time consuming and provide after-the-fact data.

2.6.3.9 Chemiluminescence. Chemiluminescent detection techniques have been employed for the measurement of atmospheric ozone. One method[20] employs the reaction of Rhodamine B that is impregnated on activated silica gel with ozone; the chemiluminescence produced is

Figure 13. Schematic diagram of a typical integrating nephelometer.


Air Sample In
Flash Lamp
Multiplier Phototube
Reference Phototube
Sampling Volume
To Blower
Electronic Control Module
Recorder

detected with a photomultiplier tube. The recommended method[21] as described in the Federal Register, Vol. 30, No. 84, employs the gas-phase reaction of ethylene and ozone; the chemiluminescence is also detected by means of a photomultiplier tube. These specific ozone chemiluminescent techniques were recently evaluated[22] and were found to be satisfactory as atmospheric ozone monitors. The gas-phase reaction is more advantageous for field use owing to its small size, simplicity of construction, and ease of operation. Figure 14 is a typical diagram of the gas-phase ozone monitor.

2.6.4 Compilation of Specific Monitors

A compilation of pertinent information on continuous air quality monitoring is presented in Appendix A. This information was gathered from the manufacturers' brochures and instrument manuals, product information bulletins, advertisements in technical journals, plus published and unpublished reports on instrument evaluation studies. This compilation is intended as a preliminary guide to assist the user in making an initial selection of two or three particular air quality instruments which will fulfill his specific needs. As noted previously, a final selection should be made only after a comprehensive evaluation is performed.

2.7 Installation of Monitors

Consideration of the location of a continuous monitor with respect to the remote station and other continuous monitors within the station is necessary. This should result in an optimum configuration whereby the instrument performance and its ease of operation is maximized. The following factors should be considered.

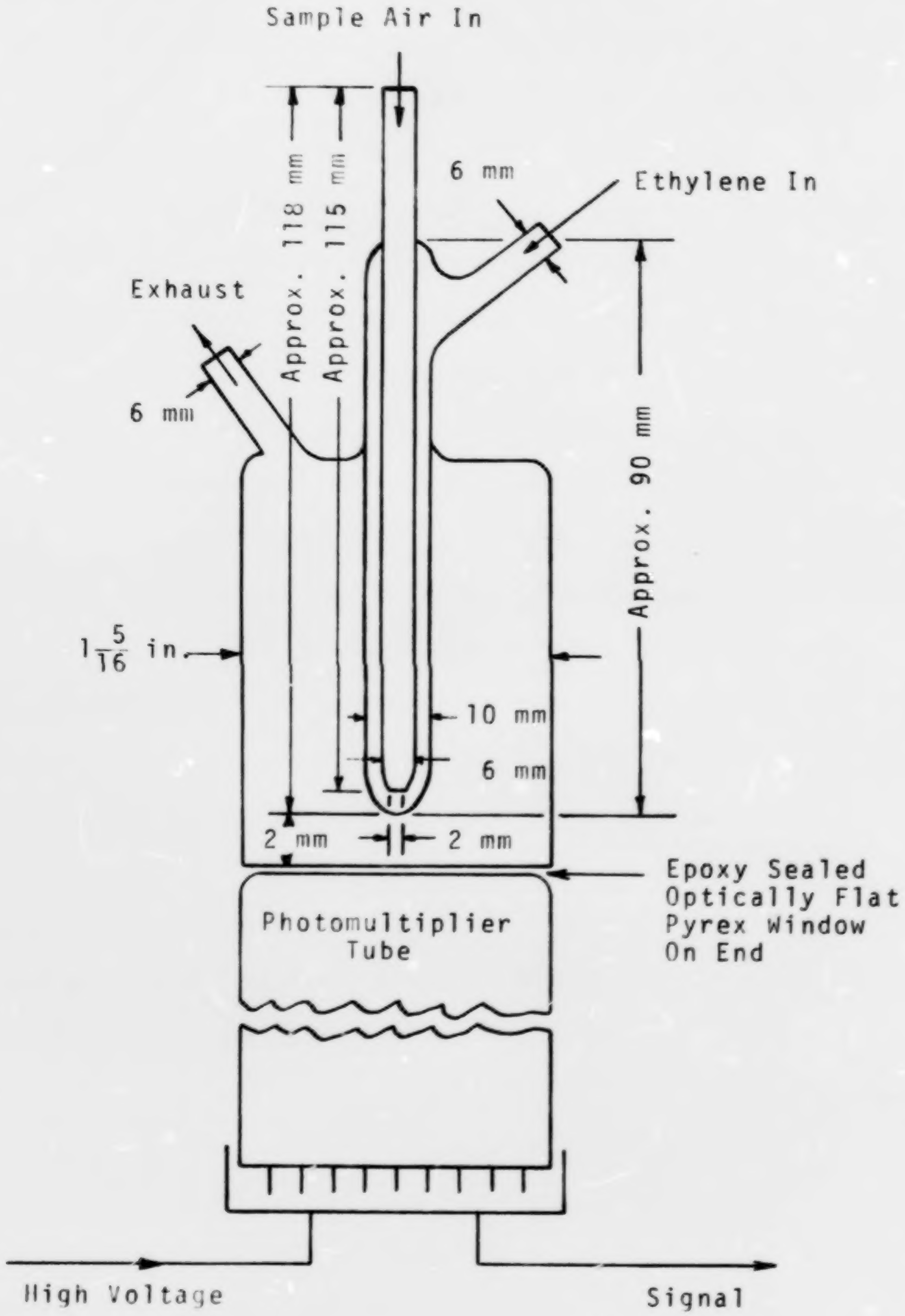

Sample Air In
Ethylene In
6 mm
Exhaust
6 mm
Approx. 118 mm
Approx. 115 mm
Approx. 90 mm
$1\frac{5}{16}$ in.
10 mm
6 mm
2 mm
2 mm
Epoxy Sealed Optically Flat Pyrex Window On End
Photomultiplier Tube
High Voltage
Signal

Figure 14. Schematic diagram of a typical gas-phase chemiluminescent ozone detector.

2.7.1 Monitor Location with Respect to Sample Manifold

Minimum length of sample intake line from manifold to monitor should be employed. This presents no problem with the conventional design since the manifold can be placed equidistant from all monitors. However, with molecular diffusion design, some monitors will be located at greater distances and in these cases the intake line will need to be cleaned or replaced more frequently. The sampling rate of the specific monitor should also be considered. Instrumentation requiring the largest sampling rate should be placed near the exhaust end of the sampling manifold. Subsequent monitors should be placed, in decending order of sampling rate, toward the inlet. This factor becomes less important with the use of conventional dynamic manifold which incorporates a blower at the exhaust end. It has no significance when the molecular diffusion design manifold is used because of the extremely large flow rate within this system.

2.7.2 Monitor Location with Respect to Operation and Servicing

Adequate space provisions for ease in operation and maintenance are mandatory. The amount of space required for each monitor will depend on its specific physical dimensions and its ease of access. If the equipment is to be rack mounted, ample room for a maintenance man behind the rack is recommended. Bench mounting requires more linear space but provides the remote station with greater flexibility since monitors can be removed or replaced with ease. In both cases, if the remote station is mobile, shock mounting is mandatory. Commercially available, aircraft-type shock mounts are recommended for this application.

2.7.3 Monitor Location with Respect to Power Requirements

All instruments and recorders should be powered by the regulated voltage circuits within the remote station. High current drain equipment, such as pumps, heating baths, etcetera should be excluded from the regulated circuits.

2.7.4 Monitor Location with Respect to Reagent, Fuel, and Waste Requirements

Equipment utilizing reagents, fuels, and waste provisions require additional space considerations. Reagent and waste storage containers in many cases require as much room as the instruments themselves. They should be located to provide easy access by the operator. In many cases the reagents are light-sensitive and therefore must be protected from light exposure. This can be accomplished by storage below the bench, within a cabinet. Instrumentation requiring hydrogen as fuel should be supplied by means of a hydrogen generator instead of storage cylinders. This is recommended from a safety standpoint.

2.8 Initial Startup of Monitoring Equipment

Prior to starting-up all continuous monitoring equipment, one all-important prerequisite must be observed: READ THE INSTRUMENT MANUAL. The specific manufacturer's operational manual is a valuable source of information; unless it is consulted, serious damage to the instrument could occur. These manuals generally provide detailed starting and operating procedures which should be followed. In addition, the following subsystem checks are recommended.

- Electrical Grounding Check--Each instrument and its related accessories should share a common ground. A continuity check with an ohmmeter can be used for this test.

- Gas Leak Check--All connections from pressurized cylinders and/or hydrogen generators should be checked for leakage. Use the soap bubble method for this test.
- Liquid Leak Check--Inspect all liquid reagent and waste connections for proper fit. This check can be accomplished by visual observation.
- Flow Rate Checks--All gaseous and liquid flow measuring devices must be calibrated (see section 3.3).

After the above checks are complete, and the instruments are operational in accordance with the specific instrument manuals, dynamic calibration procedures should be performed.

2.8.1 Preparation and Storage of Reagents

The purity, stability, and shelf life of reagent supplies for use with continuous monitors must be considered. In most applications recommended procedures for reagent preparation will be supplied by the manufacturer of the specific monitor. In general, the use of ACS reagent grade chemicals and high purity deionized water (1 megohm or higher resistance) is required. Reagents whose slight variation in purity would have an effect on the sensitivity of the method--organic dyes for example--should be purchased from a single lot in a quantity sufficient for at least one year of operation. Light-sensitive reagents should be stored in appropriate containers. Standard gas mixtures for zero and span calibration should be purchased from a supplier who has the laboratory capabilities to provide gaseous calibration to a tolerance of ±2%. One such supplier is Scott Research Laboratories.

A reference supply of these gases should be maintained for cross-reference with all future standard gases to insure continuity.

Often the stability of reagents is affected by fungus growth; to avoid this problem the addition of a fungicide is recommended.[23] The most effective fungicide found for Saltzman reagent, acid peroxide reagent, and neutral buffered KI reagent is Dowicide G.

Representatives of the Dow Chemical Company have recommended the use of Dowicide B and G used together to control slime, fungi, algae and corrosion in industrial process waters. Dowicide B and G together at a concentration of 10 ppm each should give adequate protection against fungus growth in the Saltzman reagents, peroxide, and neutral KI without affecting their chemical functions.

3.0 CALIBRATION

3.1 Role of Calibration in Air Quality Monitoring

The accuracy and validity of the data derived from air monitoring instrumentation are dependent upon the type and extent of quality control procedures employed. The first element of data quality control is instrument calibration. Calibration determines the relationship between the observed and true values of the variable being measured. Instrument calibration provides maximum quality control in collection of reliable data and is the key to comparison and utilization of data being produced by Federal, State, local, or even private air sampling networks.

Most present-day monitoring instrument systems are subject to drift and variation in internal parameters, and cannot be expected to maintain accurate calibration over long periods of time. Therefore, it is necessary to check and standardize operating parameters on a periodic basis. These are predetermined by the manufacturer and are usually listed in the operator's manual. Direct, dynamic calibration utilizing the pollutant species monitored is most desirable, although pseudo-calibrations (static) may be carried out using a material having the same effect on the sensor as the pollutant of interest.

In many instances, static calibration tests are desirable since they provide a simple, rapid means of obtaining operational data on specific components of the system. These tests are normally employed on a frequent basis, in some cases, daily. Dynamic calibration serves the purpose of establishing the actual interrelationships between the gaseous sample and the data output. Thus, it provides the evidence that all components of the continuous monitor are functioning properly to yield valid, reproducible results. Initially, frequent dynamic calibrations (e.g., once per week) will be required to establish some degree of confidence. Once this instrumental confidence is established, dynamic calibration is normally performed on a less frequent basis, perhaps monthly or quarterly depending on the specific instruments prior performance.

3.2 Dynamic Calibration

Simply stated, dynamic calibration involves the introduction of gas samples of known composition to an instrument for the purpose of producing a calibration curve or adjusting the instrument to a predetermined curve. This curve is derived from the instrumental response obtained by introducing several successive samples of different known concentrations. These standard gas mixutres are introduced in an increasing order of concentration to avoid contamination of the inlet lines and to minimize response times. The number of reference points necessary to define this relationship will depend on the nature of the instrument output. For an instrument with a linear output, a zero reference point, and two levels, approximately 30% to 90% span would be sufficient to define the instrumental performance. For nonlinear instrumentation, several more points, in some cases as many as five, will be required to adequately define the response characteristics. To insure that a negative drift does not go undetected, the zero should be set at 5% scale. Initially, dynamic calibration methods were primarily considered for laboratory application where mobility is not an important factor. Recent developments employing standardized permeation tubes and portable dilution apparatus have led to field application of dynamic calibration.

3.2.1 Permeation Tubes

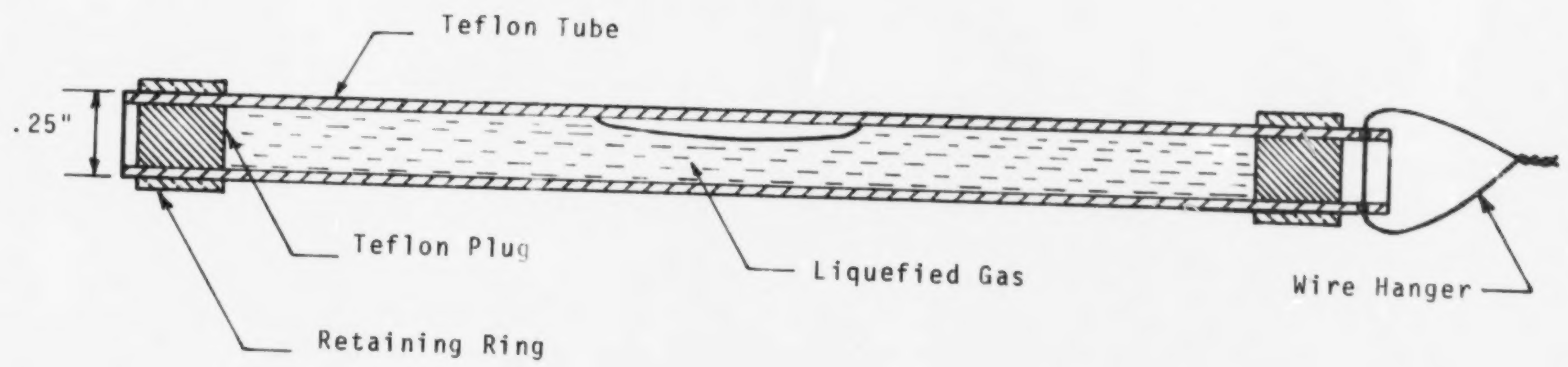
A permeation tube consists of a liquefied material contained under its own vapor pressure, in a sealed section of permeable fluorinated ethylene propylene (FEP Teflon) tubing. The gradual permeation of the enclosed material through the FEP Teflon tubing permits the dispensing of microgram quantities of that material. Following a "conditioning" period of a few hours to several weeks, permeation proceeds at a highly constant rate until the enclosed material is nearly exhausted. The rate of permeation is highly temperature dependent, but is independent of normal changes in pressure and composition of the atmosphere.

To prepare specific permeation tubes for use in calibration of SO_2 and NO_2 monitors, pure liquid SO_2 or NO_2 is contained in a tube of FEP Teflon and sealed at the ends with Teflon plugs. The plugs are held in place by flanging a small piece of stainless steel on Teflon over the plug with a swaging tool. Figure 15 is a diagram of a permeation tube.

The tubing is selected with diameter and length such that the permeation rate of the gas that it contains can be determined gravimetrically over a reasonable period of time to at least three significant figures. Techniques used in making the permeation tubes and charging them with gas are described by O'Keefe and Ortman.[24]

Calibration of a liquid-filled tube consists of collecting weight data losses over a period of approximately six weeks. Between

Figure 15. Permeation tube.


Teflon Tube
.25"
Teflon Plug
Retaining Ring
Liquefied Gas
Wire Hanger

weighings, the tube must be maintained at a controlled temperature slightly above ambient, usually 25 ± 0.1°C, and low humidity using silica gel or a comparable desiccant. Weight losses per unit of time are expressed as permeation rates.[25,26] Calibrated permeation tubes are commercially available from Metronics Associates, Inc., and Analytical Instrument Development Co.; and certified SO_2 tubes are available from the National Bureau of Standards.

The following equation permits calculating parts per million (V/V) pollutant in a gas flowing over a tube as a function of air flow rate:

$$C = \frac{PR}{M} \times \frac{MV}{L}$$

where

C is ppm (V/V) pollutant transferred to a gas flowing over the tube.

PR is Permeation rate at 25°C in micrograms/min.

M is Molecular weight.

MV is Molecular volume at 25°C (24.45).

L is Air flow in liters/min.

An example involving the use of this calculation is as follows:

Given: Permeation rate of SO_2 tube at 25.0°C = 2.20 μg/min

Total dilution air = 5.20 l/min.

Find: Concentration of standard gas mixture

$$C = \frac{2.20}{64} \times \frac{24.45}{5.20} = 0.16 \text{ ppm } SO_2.$$

Note: If the permeation tube temperature employed is not 25.0°C, an appropriate correction factor can be applied as presented in Table C-3 in Appendix C. This table was generated for SO_2 permeation tubes only and if it is to be used for other tubes, its applicability should be determined first.

3.2.1.1 Permeation Tube Dilution Apparatus. Figure 16 illustrates an apparatus for producing controlled low level concentrations of standard gas mixtures employing permeation tubes. The system employs a gravimetrically calibrated permeation tube and purified air as a diluent.

The diluent gas is prepurified cylinder or ambient air from which pollutants and moisture have been removed by passing through scrubbing columns filled with 8- to 12- mesh activated charcoal and a desiccant.

The diluent air is passed through a needle valve and a precision rotameter, calibrated within ± 1% by a wet-test meter, to control and measure the flow. A purge flow of purified air (approximately 0.5 l/min.) is passed through the temperature conditioning coil and over the permeation tube, which is held in a Pyrex glass holder, submerged in a water bath, and controlled to 25 ± .1°C. The diluent air and the purge gas stream are mixed in the mixing bulb. The resultant pollutant concentration is varied by adjusting the needle valve to control the air stream flow rate. A vented Pyrex manifold distributes this concentration to the instrument at atmospheric pressure. All surfaces in the distribution system that contact the test atmosphere must be made of Teflon or Pyrex glass.

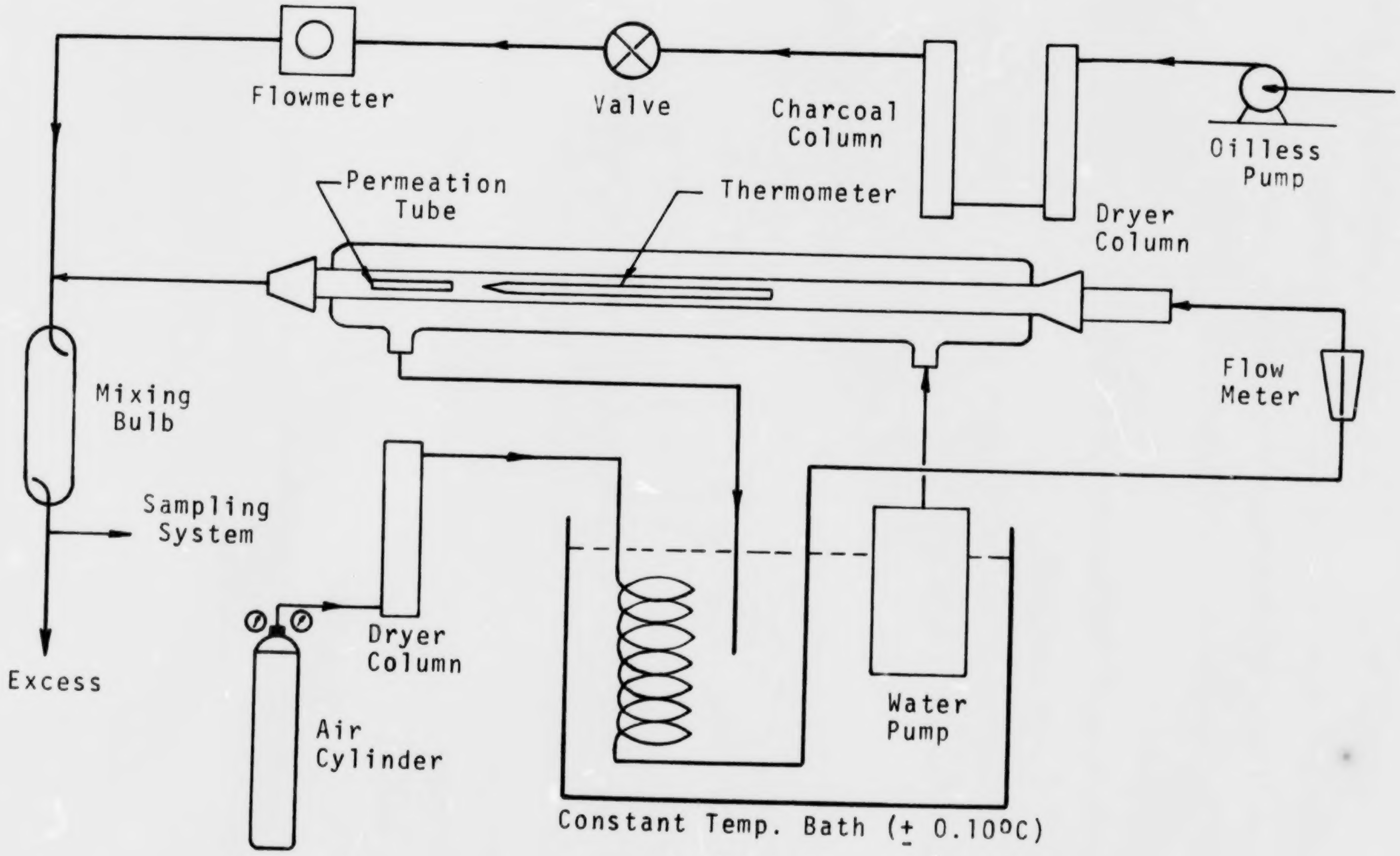

Flowmeter
Valve
Charcoal Column
Oilless Pump
Permeation Tube
Thermometer
Dryer Column
Flow Meter
Mixing Bulb
Sampling System
Excess
Dryer Column
Air Cylinder
Water Pump
Constant Temp. Bath (± 0.10°C)

Figure 16. Permeation tube dilution apparatus.

A portable calibration apparatus has been developed for field application. A schematic diagram of this apparatus is shown in Figure 17. The apparatus was designed specifically for portability; therefore, since it does not include a thermostatically controlled water bath, it does not permit unattended operation. The general specification, construction details and use of this apparatus have been described by Rodes.[27] This system can be built with technician-level personnel at a cost of approximately $800. Commercially available calibration systems are available from Tracor, Inc., and Analytical Instrument Development Co.

3.2.2 Standard Gases

Mixtures of stable gases can be prepared to exact concentrations in pressurized cylinders. Following a confirmatory analysis by a referee laboratory, they can be used as standard calibration gases. Commercially available mixtures of methane in air or nitrogen and mixtures of carbon monoxide in helium or nitrogen have been found to be very stable over periods of several months. Span calibration of carbon monoxide and hydrocarbon monitors is achieved by direct introduction of these standard gases to the monitors. Normally a manifold arrangement, such as shown in Figure 18, is employed to maintain the appropriate sampling conditions.

Preparation of cylinder-stored standards of the more reactive gas mixtures such as sulfur dioxide or nitrogen dioxide in air cannot be achieved since these gases are unstable at the required concentrations. Higher concentrations of SO_2 or NO_2, in the 0.5 percent range, have been found to be stable for several months providing inert diluent

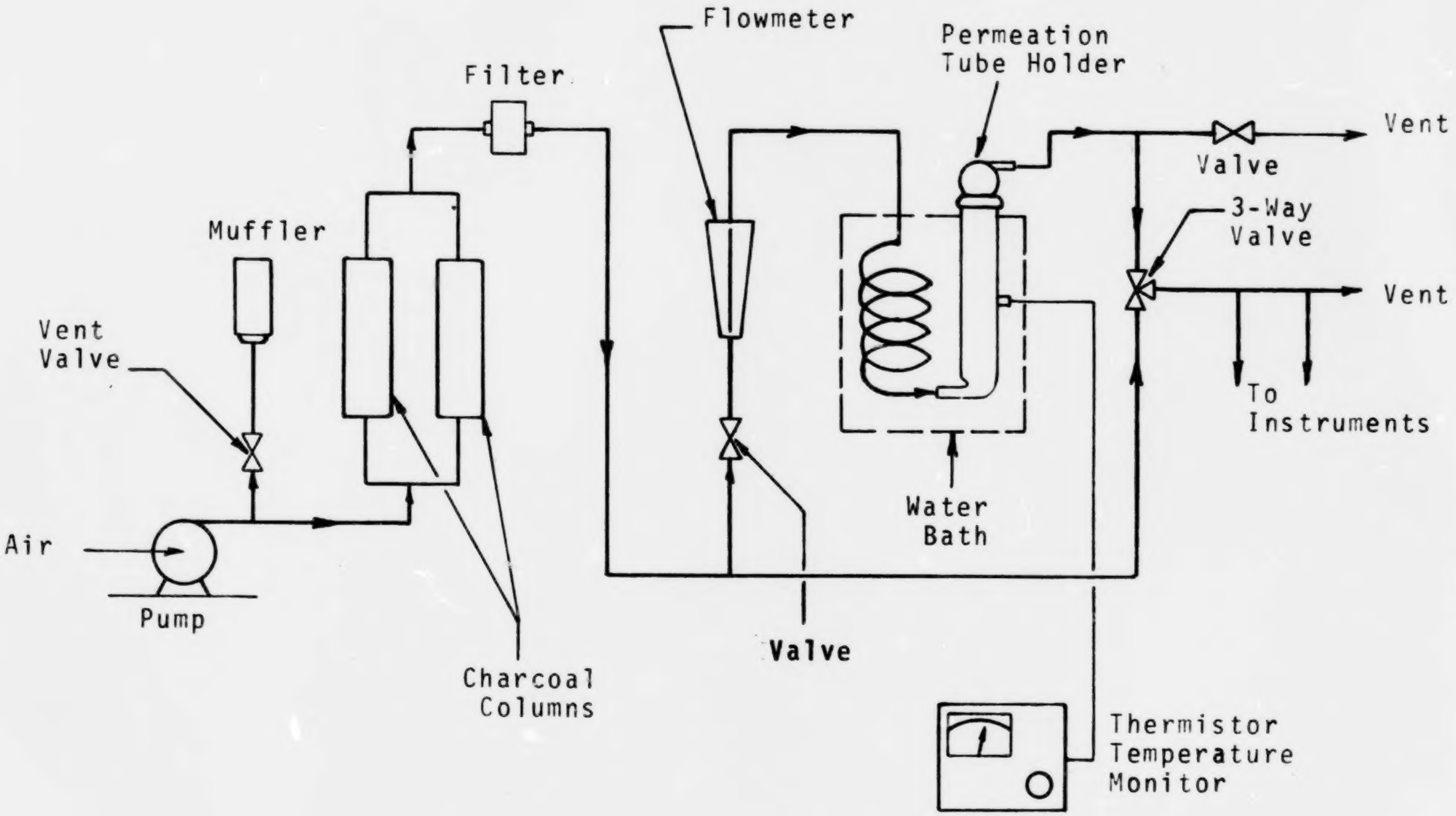

Flowmeter
Permeation
Tube Holder
Filter
Vent
Valve
3-Way
Valve
Muffler
Vent
Valve
Vent
To
Instruments
Air
Pump
Water
Bath
Valve
Charcoal
Columns
Thermistor
Temperature
Monitor

Figure 17. Portable calibration apparatus for use with permeation tubes.

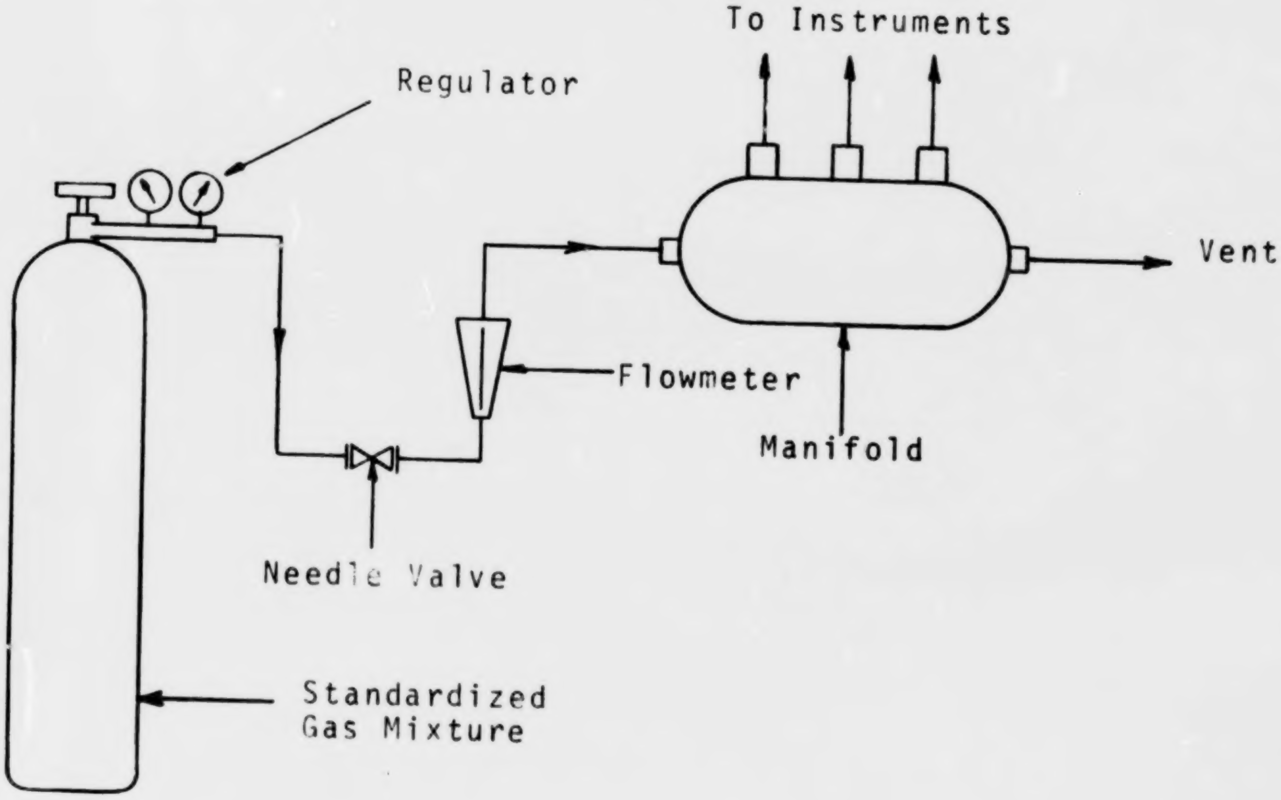

To Instruments
Regulator
Vent
Flowmeter
Manifold
Needle Valve
Standardized Gas Mixture

Figure 18. Distribution system for use with standard gases.

gas and clean storage cylinders are used. Mixtures of these gases can be diluted to lower calibration levels by means of a dilution board device.[28,29]

The NO_2 or SO_2 dilution board used for dynamic referee analysis (Figure 19) combines a simple flow proportioning system with a mixing chamber and a self-contained sampling train for manual sampling and analysis. The gas proportioning system has two inlet connections: one for a concentrated gas mixture (prepared and transported in a stainless steel cylinder) and the other for diluent air supplied by a pump, preceded by columns containing activated carbon and soda lime to remove impurities. Each component gas flows through a needle valve and rotameter before the two are combined in a mixing chamber. The diluted mixture then passes simultaneously to the manual sampling system and to the analyzer being calibrated. A series of concentrations of the calibration gas can be produced by varying the flow ratios. As long as the two flowrates are kept constant, the produced mixture is uniform. Fritted glass bubblers are used for collection of NO_2, while standard impingers are used for SO_2.

The ozone calibration apparatus differs from the one described above in that it uses an ozonizer[30] (see Figure 20), which consists of an eight-inch pencil type mercury lamp which irradiates a 5/8 inch quartz tube through which clean air flows at 5-10 liters/min. The generation of ozone may be varied from 0-1 ppm by variable shielding of the lamp envelope. The flowrate is controlled by a needle valve and measured by a rotameter. The ozonized air passes to a manifold

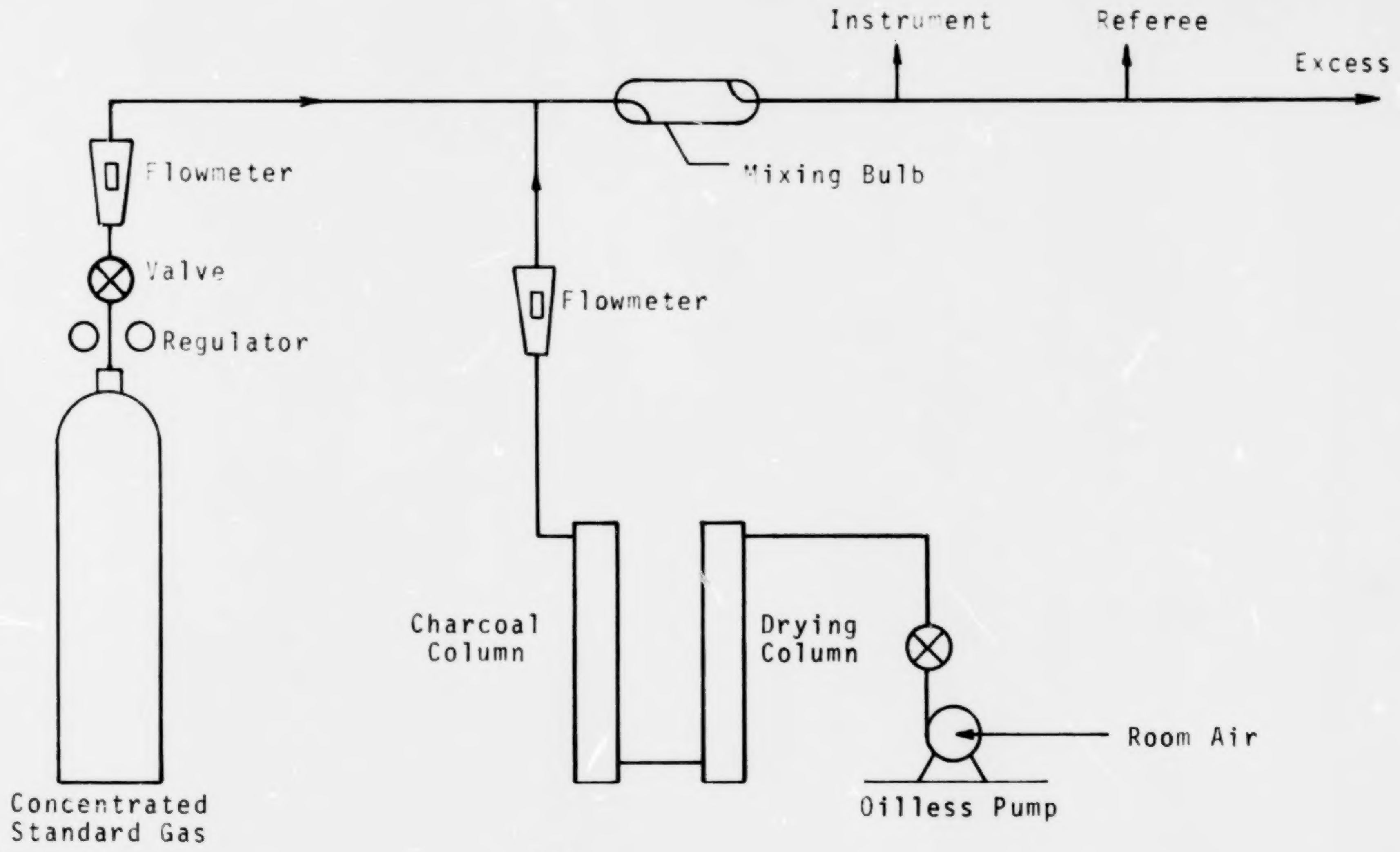
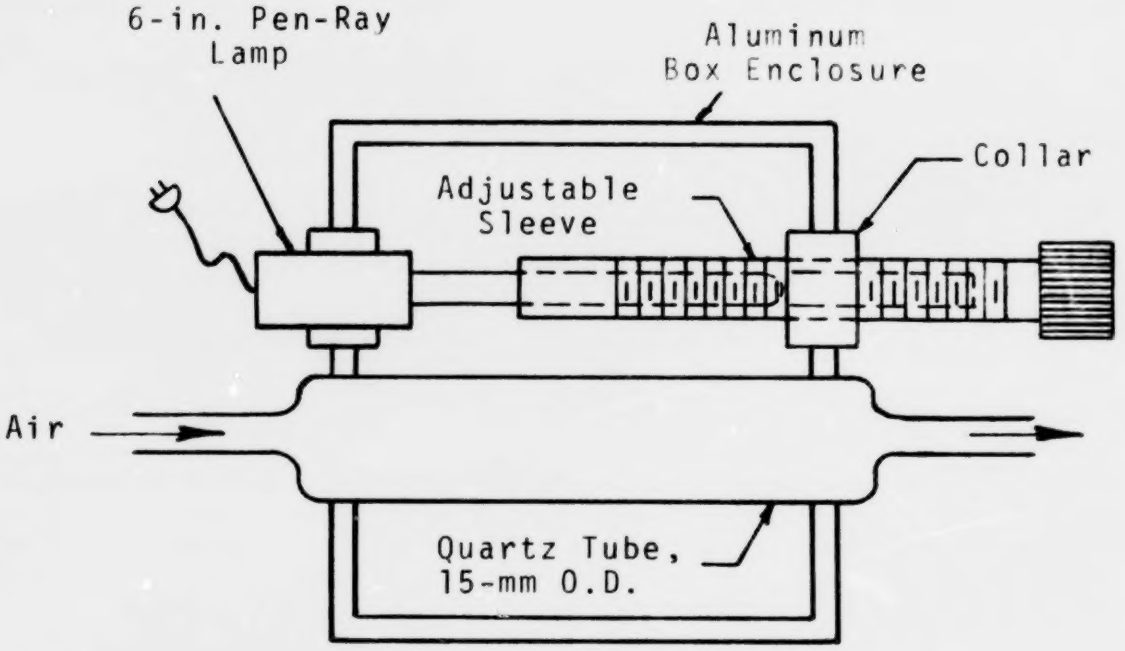

Instrument
Referee
Excess
Flowmeter
Mixing Bulb
Valve
Flowmeter
Regulator
Charcoal Column
Drying Column
Room Air
Concentrated Standard Gas
Oilless Pump

Figure 19. Dilution board device.


6-in. Pen-Ray Lamp
Aluminum Box Enclosure
Collar
Adjustable Sleeve
Air
Quartz Tube, 15-mm O.D.

Ozone Source

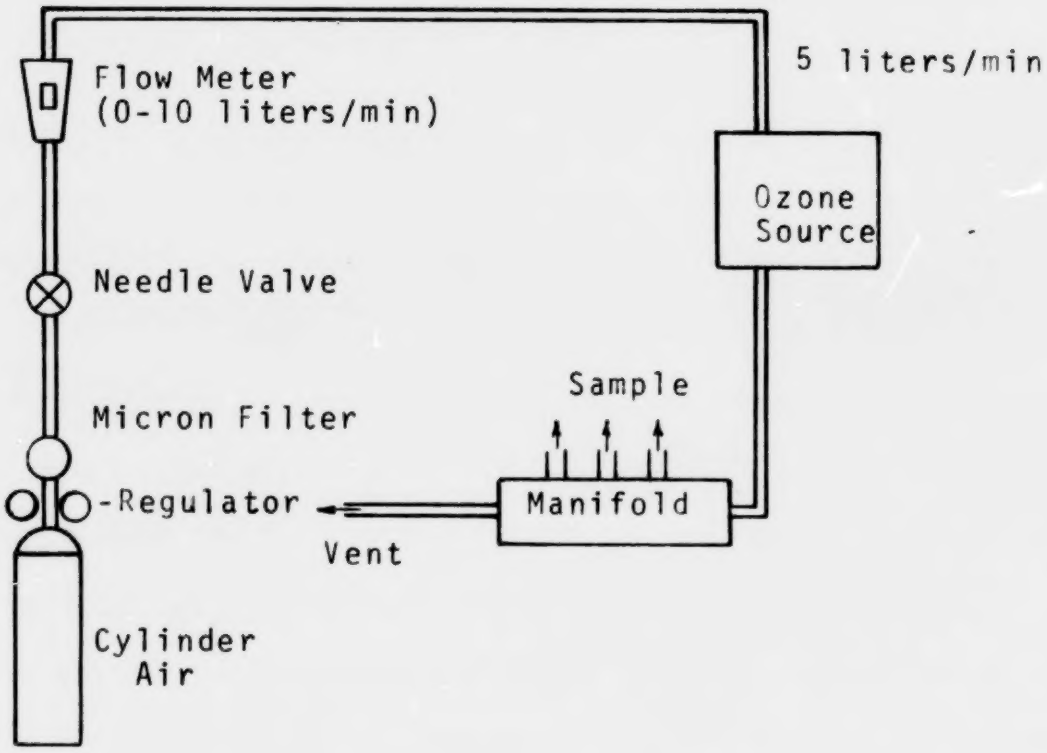

Flow Meter (0-10 liters/min)
5 liters/min
Ozone Source
Needle Valve
Sample
Micron Filter
-Regulator
Manifold
Vent
Cylinder Air

Figure 20. Ozone source, dilution, and manifold system.

from which the monitor under test draws its sample. Standard impingers are used to sample the test atmosphere. A certified ozone generator is available from the National Bureau of Standards.

Wet chemical analysis of the sample collected simultaneously in the manual bubbler provides data for the preparation of the calibration curve, Methods which can be used for the preparation of calibration curves for SO_2 and NO_2 are published by the Health Laboratory Service[31,32] while the calibration methods for oxidant is included in the reference method for photochemical oxidants published by the Environmental Protection Agency.[11]

Another method of dynamic calibration commonly used prior to the advent of the permeation tube employs standard gas mixtures prepared and contained in inert, impervious plastic bags.[33] Polymeric plastic films such as Teflon, Mylar, Tedlar, Scotchpak, Kef-F, Saran and cellophane have been used for this application. Of these materials, Teflon, Mylar, and Tedlar have been found to be the most desirable for overall applications.

Gas mixtures are prepared in bags by metering a large volume of diluent gas into the bag and then injecting a small amount of concentrated gas from a syringe through a serum stopper attached to the inlet fitting. Mixing is accomplished by kneading the bag. Conditioning of the bag for several hours with the same magnitude of concentration of pollutant prior to its use is necessary to avoid losses through adsorption on the walls of the bag.

If the volumes of diluent and sample gases have been accurately measured, and if the mixtures are stable for the particular gas mixture-bag combination selected, the standard can be assumed to contain its calculated concentration. Practically, the concentration should be verified by a referee wet chemical method.

3.3 Calibration of Flow Parameters

Most automatic monitors have gaseous flow systems which must be maintained at a fixed rate for optimum operation. These systems must be maintained, calibrated, and adjusted to the manufacturers' recommended specifications to provide accurate service. Two methods for gas flow calibration are in general laboratory use: primary calibration using a wet test meter and secondary calibration using a precalibrated mass flowmeter. The use of the mass flowmeter results in more rapid measurements, but it is subject to instrumental drift and should be periodically checked with a wet test meter. All other flowmetering devices such as rotameters should be checked against a wet test meter. Another more rapid approach to insuring the performance of mass flowmeters in routine usage is to reserve one calibrated mass flowmeter at the central laboratory as a reference and check the field meters against it before using. The test meter is placed upstream to the instrument's intake system in order to maintain atmospheric pressure through the device. Several data points (at least 5) are obtained by varying the control valve on the instrument. The volumetric flow data is plotted on linear graph paper against the rotameter setting to obtain a flow rate calibration curve. A typical rotameter calibration data sheet is presented in Figure 21. A typical flow rate calibration curve is presented in Figure 22.

Instrument ______________________________

Rotameter Serial No. ______________________________

Calibrated With ______________________________

Location ______________________________

Temperature ______________________________°C

Atmospheric Pressure ______________________________mmHg

Relative Humidity ______________________________%

Calibrated By ______________________________

Test Point	Rotameter Reading	Total Flow l	Time min.	Flow rate l/min.
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Figure 21. Rotameter calibration data sheet.

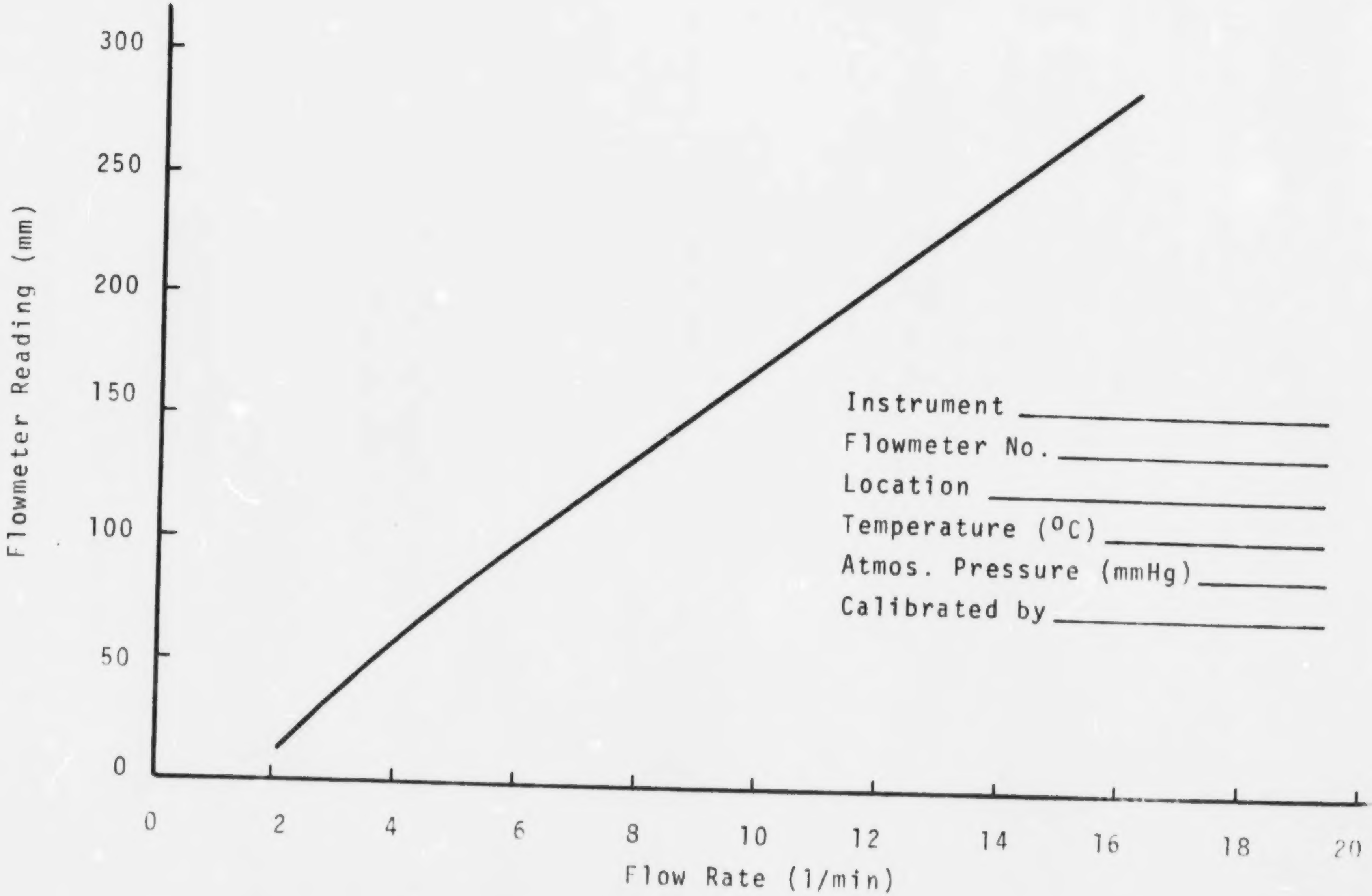


Figure 22. Typical rotameter calibration curve.

Liquid flow calibration is achieved by means of the volumetric displacement technique. This method consists of measuring the volume of liquid displaced by the reagent pump over a prescribed and measured unit of time. Often the reagent transfer plumbing must be disconnected at a point beyond the liquid flow rotameter, preferrably in the waste line, and directed into a graduated cylinder. Care must be exercised to insure that the pressure head remains constant. Calibration curves for liquid flow systems are unnecessary if the instrument is equipped with a fixed-rate solution pump. Instruments with an adjustable solution metering pump, liquid rotameter, and flow control system should be calibrated throughout their operational range.

The flow parameters must be calibrated and adjusted to the prescribed settings prior to dynamic calibration. Once these variables are fixed they should be recorded on the front panel of the continuous monitor for ready reference during the periodic operational checks described in section 4.0.

3.4 Static Response Checks

Modified calibration methods are applied under static instrumental conditions to check instrumental response. Normally, no sample air flow is permitted when utilizing these techniques. The reagent flow system is sometimes activated to introduce the test solution into the detector. Static methods, if used on a routine basis, provide a rapid means to determine instrumental operational response. These data, when compared to previously obtained values, provide a good indication when maintenance and dynamic calibration procedures are necessary. In general static methods have found wide usage as a rapid standardization check employing a single reference point, since a minimum of equipment, time, and skill are required.

3.4.1 Static Chemical Methods

A widely used method of static response employs standard solutions which are chemically equivalent to the pollutant. In this procedure, dilutions of a standard solution are introduced into the measuring cell of the analyzer. A calibration curve can be plotted from points obtained by comparing the instrument response with the equivalent pollutant concentration.

A similar static method employs standard solutions such as dyes and electrolytes which are not necessarily chemically equivalent to the reacted reagent, but which reproduce its measured property, such as optical density or electrical conductivity. Such solutions are useful only when their pollutant equivalents have been determined on a properly calibrated instrument.

3.4.2 Static Electrical Methods

Because so many types of circuitry are employed in the detector section of continuous monitoring instruments, it is necessary to use caution when employing static electrical checks on these systems. The manufacturer's manual should be consulted as to the type of signal provided, i.e., current, voltage, or resistance. In most cases electrical signals can be simulated with commercially available test equipment. This mode of static electrical calibration serves the purpose of standardizing the various electronic and recording systems associated with the continuous monitor.

3.5 Dynamic Response Checks

The response of many continuous monitors--such as those for the determination of hydrocarbons, sulfur dioxide, nitrogen dioxide, and oxidants--can be dynamically checked by relatively simple means. output from an ultraviolet light source could be used for all oxidant instruments, while the appropriate permeation tube--SO_2, NO_2, and butane (for hydrocarbons) can be used to check the response from the corresponding instrument. This technique is recommended only as a *rapid* dynamic response check, since errors can result from background levels of pollutants in the ambient air used as the diluent gas, and from the fluctuations in the temperature and moisture control of the permeation tube.

4.0 OPERATION

4.1 Operational Performance Log--Check Lists

Often problems encountered during operation of atmospheric analyzers are slow in developing and therefore go undetected for some time. These minor malfunctions cause inaccurate readings and eventually lead to instrument downtime unless a routine method of instrument checking and performance logging is established to identify them before they become severe. Thus, an organized procedure of operational logging and instrument checking must be established to define the chemical, physical, and electronic operational parameters on a continuing basis. It is highly recommended that the operational history of each specific monitor be routinely recorded, preferrably in individual logs. These performance logs should be designed in a standardized format to insure uniformity in recording all system checks, maintenance requirements, maintenance schedule, calibration data, and all other pertinent information. A concise historical record of these parameters can be attained provided that the log book is properly organized. One approach is to record these functions with reference to a predetermined operational period. Each operational period would occupy a separate section within the log book, e.g., daily, weekly, monthly, quarterly, etc. The specific information to be logged in each section would be dependent upon the operational characteristics of each individual instrument. This specific information can be developed from the manufacturer's instrument manual. However, for any monitor, general information can be defined with respect to the operational periods as follows:

(a) Daily operational log requirements

- ° Instrument settings--All pertinent instrument settings, such as operational function switches, gain and zero-adjustment knobs, etc., should be included.
- ° Visual inspection of the past 10 to 30 hours of strip chart data.
- ° Flow parameters--Liquid and gaseous flow rates should be verified.
- ° Peripheral support items--Supplies such as reagents, fuels, recorder paper and ink, waste reservoirs, etc., should be inspected.
- ° Zero drift measurements--Zero measurements should be included.
- ° Span drift measurements--Span measurements should be included.
- ° Static operational checks--Static checks to verify the operation of the various components of the total system should be employed.
- ° Specific routine maintenance--Maintenance schedules for daily use should be developed from the manufacturer's instrument manual and regularly employed.

(b) Weekly operational log requirements

- ° Peripheral support items--Same requirements as above.
- ° Span measurements--Single-point dynamic span checks are recommended.

- Specific routine maintenance--Maintenance schedules for weekly use should be developed from the manufacturer's instrument manual and employed.

(c) Monthly operational log requirements

- Peripheral support items--Same requirements as above.
- Specific routine maintenance--Maintenance scheduled for monthly use should be developed from the manufacturer's instrument manual and employed.

(d) Quarterly operational log requirements

- Specific routine maintenance--Maintenance schedules for quarterly use should be developed from the manufacturer's instrument manual and employed.
- Calibration--Full range dynamic calibration procedures should be developed from section 3 and employed quarterly.

In order to illustrate this systematic approach, the following series of operational log forms (Figures 23, 24, 25, and 26) have been developed for use with a conductivity monitor for SO_2, although this is not a recommended method. In addition to the routine operational sections, a final section cataloging major maintenance and parts replacement is suggested. With this information a fatigue sequence or failure rate of components can be established. Future requirements for maintenance can be predicted and scheduled thus avoiding instrument downtime.

4.2 Data Logging

4.2.1 Role of Data Logging

The voltage output from a continuous analyzer must be input to a data logger in order to obtain a usable record of the ambient

Date __________ Time __________ Operator ______________

Instrument Ident. ________________ Zero Set at __________%

Station Ident. __________________ Instrument Range _______

Air Flow Set at ___________ l/min.

Reagent Flow Set at ________ ml/min.

CHECK LIST

- ☐ Check operational settings.
- ☐ Check system for leaks--air and liquid.
- ☐ Check recorder for "live trace" and time synchronization.
- ☐ Check reagent supply.
- ☐ Check waste reservoir.
- ☐ Check recorder supplies (paper and ink).

Air flow rate found at ________l/min. Set to ________l/min.

Zero check ______%. Chart set to __________% chart.

Record of electrical static check ________ohms = ______% chart.

Remarks and/or actions required to rectify unsatisfactory conditions:

Figure 23. Daily operational log (conductivity monitor).

Date __________ Time __________ Operator _____________

Instrument Ident. _______________ Station Ident. ________

CHECK LIST

[ ] Replenish reagent supply.

[ ] Empty waste reservoir.

[ ] Remove recorder chart and process data.

[ ] Check solution pump rate.

Dial setting _________ Flow Rate _________ml/min.

Remarks and/or actions required to rectify unsatisfactory conditions.

Figure 24. Weekly operational log (conductivity monitor).

Date _________ Time __________ Operator ______________

Instrument Ident. _____________ Station Ident. ________

CHECK LIST

[ ] Remove and clean inlet sample tubing.

[ ] Remove and clean reagent tubing if necessary.

[ ] Remove and clean rotameter if necessary.

[ ] Tighten all fittings if necessary.

[ ] Change absorbent in zero scrub column.

[ ] Oil liquid and air pumps.

Remarks and/or actions required to rectify unsatisfactory conditions:

Figure 25. Monthly operational log (conductivity monitor).

Date ________ Time ________ Operator ____________

Instrument Ident. __________ Station Ident. ________

CHECK LIST

☐ Electronic check of recorder zero and fullscale response.

☐ Clean reagent reservoir.

☐ Clean and flush conductivity cell.

☐ Clean and calibrate sample rotameter.

☐ Clean and flush contact column.

☐ Clean sample manifold.

☐ Replace carbon vanes in air pump.

☐ Change vibration pads on air pump.

☐ Replace solution pump with a refurbished unit.

Dial Setting ____ Flow Rate ____ml/min.

Dynamic calibration

Concentration ppm	Response % Chart

Remarks and/or actions required to rectify unsatisfactory conditions.

Figure 26. Quarterly operational log (conductivity monitor).

concentrations of a pollutant. Typical data logging systems employ strip chart, punched paper tape and magnetic tape recorders. As indicated earlier in the manual, the SAROAD system has been designed to facilitate the transference of strip chart data to hand recorded forms and from these to punch cards. A guideline manual has been generated to detail this step-by-step procedure.[34] Data loggers may be located at the field sampling station, at a central command station or a combination of both. Some recently installed systems transmit data from the remote sensor via telephone lines directly to a computer. This computer system could be either a small computer dedicated to the support of the continuous monitoring system or a large general purpose computer used in a time-sharing mode. For this application a large general purpose computer is not a good idea. Generally the priority of the continuous recording might get displaced, preventive maintenance downtime destroys required data, and the continual program shifting may destroy the systems operation. A small dedicated computer is better suited for this type of operation.

4.2.2 Logging Pollutant Level

The voltage output from a continuous analyzer can be recorded in a variety of ways. A description of three currently used techniques is given below.

4.2.2.1 Continuous. A continuous trace of the output signal can be recorded on a strip chart. The deflection of the pen on the strip chart can then be related to the ambient concentrations of the pollutant through either a linear or nonlinear function by means of a calibration curve. The continuous trace provides a visual record of the pollutant concentration fluctuation over a specified time period. Peak pollutant concentrations as well as time averaged concentrations can be read from the strip chart.

4.2.2.2 Instantaneous. Another way to record the output from the sensor is to pick up the instantaneous signal at precise increments of time. The voltage is digitized by an analog-to-digital converter and recorded on punched paper or magnetic tape. Because of short time fluctuations in ambient concentrations as well as background noise in the system, it is advisable to record instantaneous values at time intervals of 5 minutes or less.

4.2.2.3 Time Averaged. The high frequency fluctuations in the sensor signal, caused by background noise and short term variations in concentrations, can be filtered out by including an electronic integrator in the data logging system. The integration period can be varied from a few seconds to perhaps an hour. In order to provide some information about short term pollutant concentrations, integration times of 15 minutes or less are advisable. The integration method works only for linear output signals. Integrating a nonlinear response is invalid.

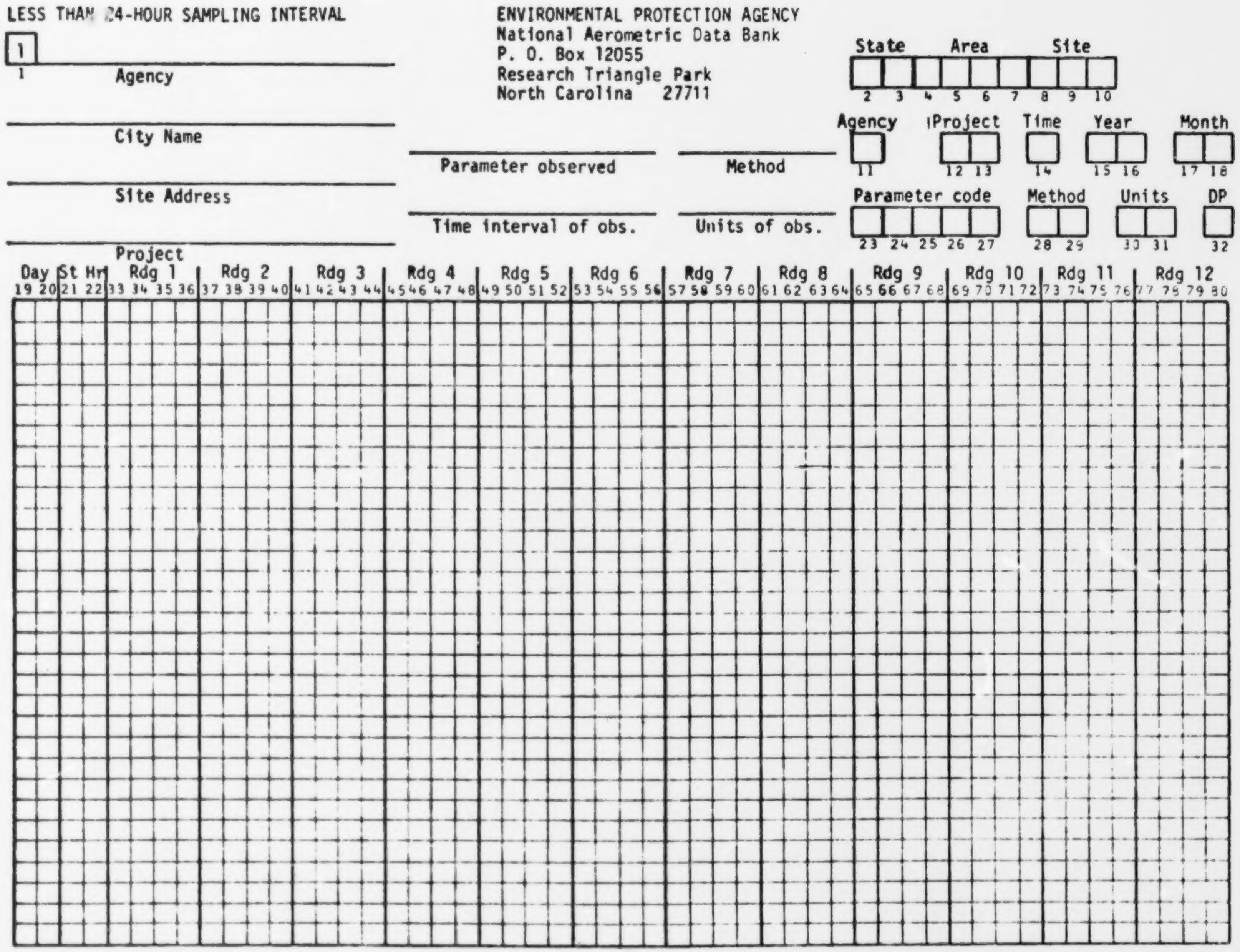
4.2.3 Data Reduction and Validation

The record produced by the data logging system requires reduction and processing to obtain pollutant concentrations in appropriate units. Experience has also shown that operational difficulties may result in the production of invalid data from continuous analyzers. Thus data validation is an extremely important part of data processing activities. Methods of handling air quality data ranging from manual to fully automated are discussed below.

4.2.3.1 Manual. Measurements of pollutant concentrations recorded on strip charts must be reduced to a set of discrete values. This reduction is a manual operation requiring an individual to scan the entire strip chart to determine the appropriate time-averaged concentrations. Typically, hourly average and daily peak concentrations are read from the chart. The daily peak concentration is usually taken to be the maximum 3 to 5 minute concentration for the day. Determining average concentrations by visually averaging the trace over a given time period is admittedly subjective; however, experience has shown that individuals who read charts in a routine basis become quite adept and can in fact determine the average within the limits of accuracy of the sensor system.

Concentration data obtained from reading strip charts can be recorded for further use in two ways, (1) on preprinted forms by hand, and (2) on punched charts by means of a chart reader coupled with a key punch. The SAROAD format being used for hand recording hourly and 24-hour data is presented in Figures 27 and 28. Usually, hand recorded data are transferred to punched cards for subsequent report preparation and statistical analysis.

Since the reduction of data from strip charts, either manually or with the aid of a chart reader, is a very tedious task, it should be performed by trained clerical personnel. In order to maintain high quality data reduction, it is good practice to have strip charts edited by a skilled technician or even technical personnel who are familiar with the operation of the sensor. Through the editing process, comments necessary to correct individual readings can be entered on the chart.



LESS THAN 24-HOUR SAMPLING INTERVAL

1
1 Agency

City Name

Site Address

ENVIRONMENTAL PROTECTION AGENCY
National Aerometric Data Bank
P. O. Box 12055
Research Triangle Park
North Carolina 27711

Parameter observed

Method

Time interval of obs.

Units of obs.

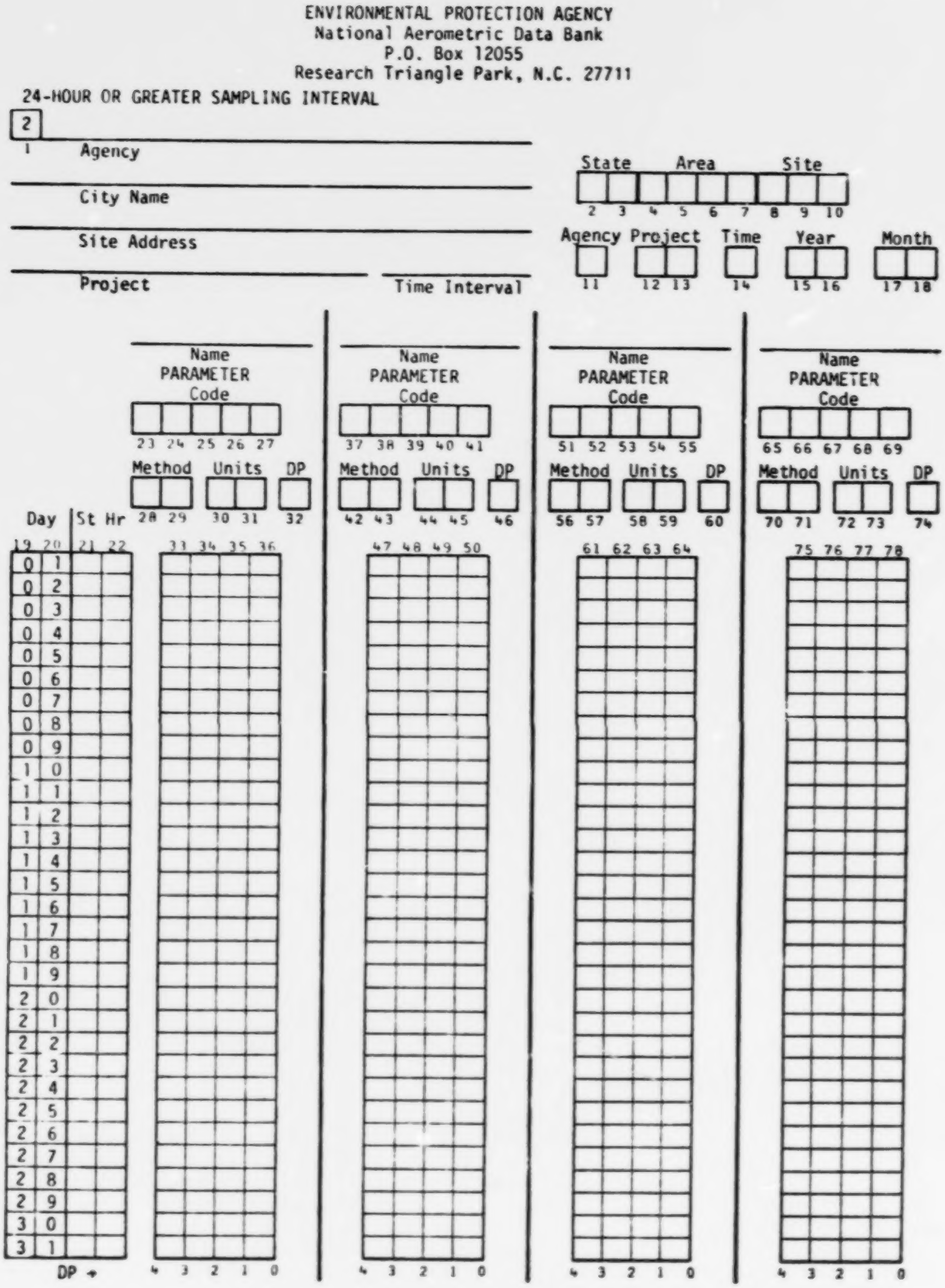
State ☐☐ 2 3 Area ☐☐☐☐ 4 5 6 7 Site ☐☐☐ 8 9 10

Agency ☐ 11 Project ☐☐ 12 13 Time ☐ 14 Year ☐☐ 15 16 Month ☐☐ 17 18

Parameter code ☐☐☐☐☐ 23 24 25 26 27 Method ☐☐ 28 29 Units ☐☐ 30 31 DP ☐ 32

Day	St Hr	Project Rdg 1	Rdg 2	Rdg 3	Rdg 4	Rdg 5	Rdg 6	Rdg 7	Rdg 8	Rdg 9	Rdg 10	Rdg 11	Rdg 12
19 20	21 22	33 34 35 36	37 38 39 40	41 42 43 44	45 46 47 48	49 50 51 52	53 54 55 56	57 58 59 60	61 62 63 64	65 66 67 68	69 70 71 72	73 74 75 76	77 78 79 80

Figure 27. SAROAD hourly data form.



ENVIRONMENTAL PROTECTION AGENCY
National Aerometric Data Bank
P.O. Box 12055
Research Triangle Park, N.C. 27711

24-HOUR OR GREATER SAMPLING INTERVAL

2
1

Agency

City Name

Site Address

Project

Time Interval

State Area Site
2 3 4 5 6 7 8 9 10

Agency 11
Project 12 13
Time 14
Year 15 16
Month 17 18

Name PARAMETER Code	Name PARAMETER Code	Name PARAMETER Code	Name PARAMETER Code
23 24 25 26 27	37 38 39 40 41	51 52 53 54 55	65 66 67 68 69
Method 28 29	Method 42 43	Method 56 57	Method 70 71
Units 30 31	Units 44 45	Units 58 59	Units 72 73
DP 32	DP 46	DP 60	DP 74
33 34 35 36	47 48 49 50	61 62 63 64	75 76 77 78
4 3 2 1 0	4 3 2 1 0	4 3 2 1 0	4 3 2 1 0

Day 19 20	St Hr 21 22
0 1	
0 2	
0 3	
0 4	
0 5	
0 6	
0 7	
0 8	
0 9	
1 0	
1 1	
1 2	
1 3	
1 4	
1 5	
1 6	
1 7	
1 8	
1 9	
2 0	
2 1	
2 2	
2 3	
2 4	
2 5	
2 6	
2 7	
2 8	
2 9	
3 0	
3 1	

DP →

Figure 28. SAROAD daily data form.

Such important things as current instrument zero and span drift corrections, and periods of invalid data can be so indicated.

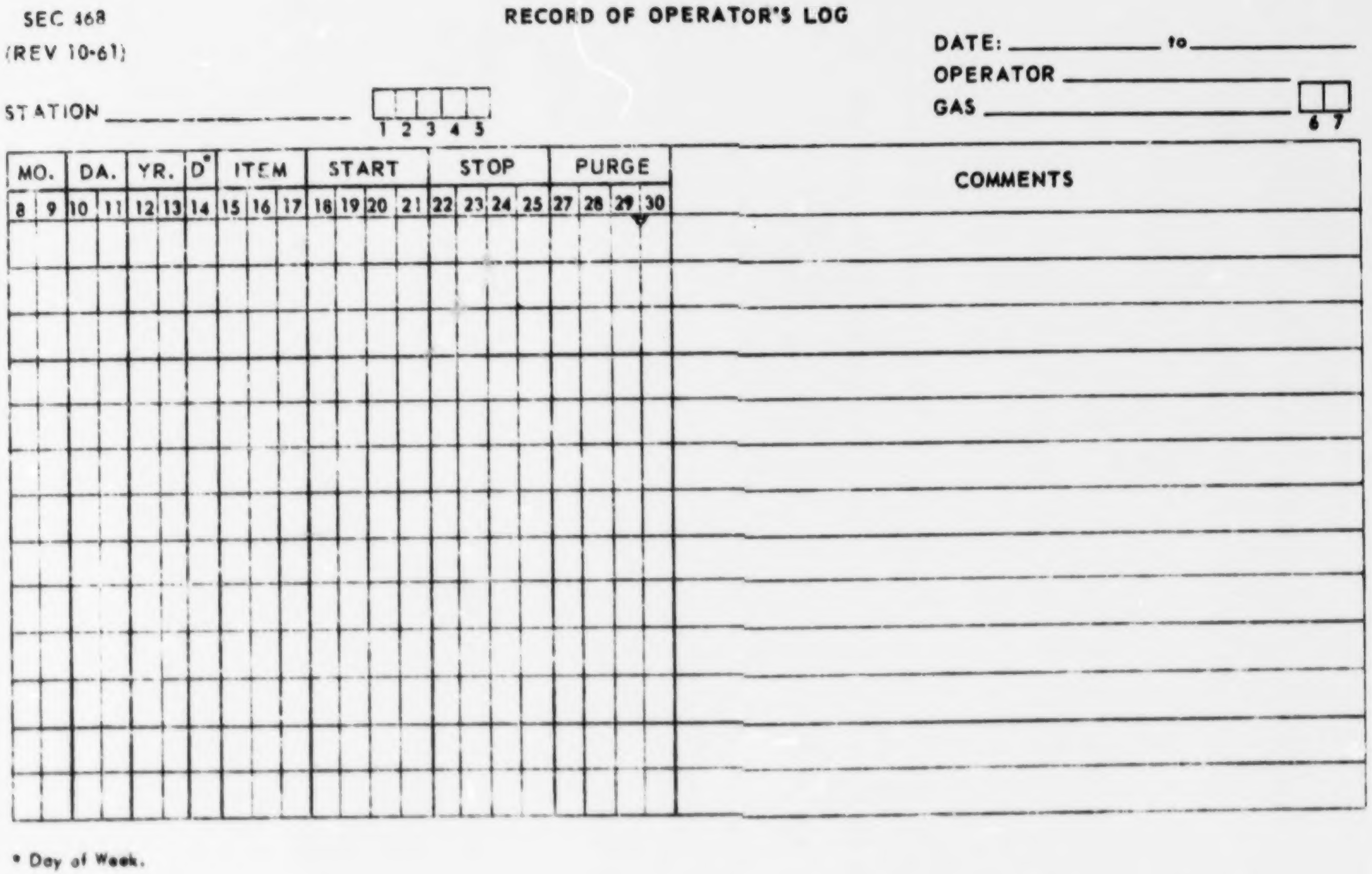
The data record on the strip chart is shown as a trace on a 0-100 percent scale. In order to facilitate the conversion to concentration units, it is customary to provide templates which can be superimposed on the strip chart.

The throughput of an individual who reduces data from a strip chart can be significantly increased through the use of an automated chart reader. In using the chart reader the strip chart is advanced over a light table. The operator aligns the horizontal (time) and vertical (concentrations) scales appropriately on the strip chart. By depressing the read switch, the data is automatically recorded on a hand copy through an electric typewriter or on punched cards through a key punch (or both).

4.2.3.2 Semiautomated System. A semiautomated data logging system is defined as one in which either paper or magnetic tape devices are used to initially record the digital output from the sensor. The recording device may be located either at the field sampling station or at a central station. In either system a new dimension is added to the problem of data reduction and validation. Data stored on tape (paper or magnetic) provides no information about ambient pollutant concentrations until a listing is prepared by the computer. If the tape recording device is located at the field station, the tapes must be physically transported to the computer center. This is usually done once or perhaps twice each week. Even when a telemetry system is used and data is stored on tape, there is no direct interface to the computer and as a result data tapes are batch processed. Such results are generally available in tabular form within 24 hours or less.

In order to properly recognize that a continuous monitor is not performing satisfactorily, it is necessary to observe the output data immediately. Thus, the remote station must be equipped with either a strip chart recorder or an electronic digital readout device. Even telemetry systems usually employ a teletypewriter to obtain an immediate printout of the transmitted data.

Data logging systems must always incorporate the necessary means to uniquely identify data as to location of sampling station, date and time of sample collection, and the pollutant being measured. In addition they should provide a means of identifying periods when the sensor is operating in a calibration mode as well as the calibration results. Likewise there is usually a mechanism by which the operator can insert "no-data" codes if the sensor is being serviced or is malfunctioning. An additional requirement to include in the system design is an external mechanism to instruct the computer to make changes or deletions of data when it is determined, after the fact, that invalid data were recorded on the tape. This is an item of concern since continuous monitoring instruments occasionally drift (or even fail) when permitted to operate unattended. A single erroneous reading can substantially alter an hourly or even daily average pollutant concentration. One way to accomplish this correction is through an operator's log which can be transferred to punched cards and read into the computer at the time of data processing (Figure 29).



SEC 468
(REV 10-61)

RECORD OF OPERATOR'S LOG

STATION ________ ☐☐☐☐☐ 1 2 3 4 5

DATE: ________ to ________
OPERATOR ________
GAS ________ ☐☐ 6 7

MO.		DA.		YR.		D*	ITEM			START				STOP				PURGE				COMMENTS
8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	27	28	29	30	

* Day of Week.

Figure 29. Operator's log.

The initial step in data processing by the computer involves the conversion of the sensor output to pollutant concentrations (μg/m^3 or ppm). At this point the computer makes the necessary adjustments for instrument calibration and deletes data known or identified as being invalid. The computer can also be programmed to make zero and span drift corrections. Prior to preparing an initial output listing of the basic measurement data, it is possible to have the computer perform a first order validation of the data. The criteria for such validation can include among other things a maximum pollutant concentration which is unlikely to be exceeded at a given sampling location, or a maximum difference between successive concentrations which is unlikely to be exceeded.

Data validation criteria should be tailored to the air quality experience of a given area. Typical values which could be used for maximum concentrations not to be exceeded for 5-minute instantaneous readings are: SO_2, 2618 μg/m^3 (1.0 ppm); CO_2, 57.2 mg/m^3 (50 ppm); NO_2, 940 μg/m^3 (0.5 ppm); total oxidant, 490 μg/m^3 (0.25 ppm); and total hydrocarbons, 9.8 mg/m^3 (15 ppm). Similarly, a reasonable criteria for questioning the difference in concentration between successive 5-minute values would be when such difference is more than 20 percent of the above maximum.

Any pollutant concentration which fails to meet the criteria is shown on the output listing along with an appropriate symbol to identify the possible reason for being invalid. The final determination as to the validity of data must be made by an individial who is knowledgeable about the location and the operation of the sensor.

After the data have been validated, it is again necessary to have an external means of communicating the appropriate information to the computer. An example of recording forms from which punched cards can be prepared was presented in Figures 27 and 28.

4.2.3.3 Computer Controlled System. A network of continuous monitoring stations can be operated under the control of an on-line computer located at a central facility. In this system the computer is programmed to sequentially interrogate the remote stations at some predetermined interval. When a remote station receives a command to transmit, a scanning device interrogates each sensor and assembles the information into a message which is then transmitted to the receiver at the central station where it is immediately input to the computer. When the computer reads the end-of-message, it signals the next station, or if all stations have been interrogated, waits for the beginning of the next cycle.

The on-line control unit at the central station may be either a small computer totally dedicated to functioning as a control module or a time-shared general purpose computer. When a small computer is used as the control module, it is still necessary to have access to a general-purpose computer. This computer is used to maintain historical files, prepare routine reports, and perform retrospective statistical analyses.

The decision as to the type of computer to be used as the control module is determined to a large extent by the way in which the signal from the remote sensor is presented to the telemetry system for transmission. The signal output from most sensors is an analog voltage.

If the transmission distance is more than a few miles, or if there are several sensors at a remote station, it is necessary to convert the signal to a digital voltage. There are two ways of handling the conversion: (1) the instantaneous analog voltage may be converted to digital at short time intervals (e.g., each minute), or (2) the analog signal may be input to an electronic integrator and the output from the integrator converted to digital.

When instantaneous sensor outputs are transmitted to the central station, the on-line computer accumulates the values for each sensor over an interval of time (usually one hour or less) and computes a time-averaged pollutant concentration. The average concentrations are then printed to obtain a hard copy which provides a continuing record of air quality. The on-line computer can be used to calculate running-average concentrations (e.g., 6 hrs., 12 hrs., 24 hrs., etc.). When the basic time-averaged concentrations are calculated, they are also written on computer-compatible magnetic tape. This tape is processed by the large general-purpose computer to update the master data files. If the sensor output is integrated prior to transmission of the central station, the computer is required to poll the remote station much less frequently.

A computer-controlled system must contain provisions for validity checks on the data. Errors of transmission are usually identified by parity checks. A more serious problem occurs when the sensor is malfunctioning and produces an output signal that is not representative of the ambient concentration of the pollutant. It is possible to program the computer to validate incoming data. As each pollutant concentration is calculated by the computer, it can be checked against some maximum concentration which is unlikely to be exceeded. If the maximum is exceeded, the calculated value can be tagged with an appropriate symbol on the ouput listing. Secondly, successive pollutant concentrations can be compared and, if there is a large difference, the most recent value can be tagged with an appropriate symbol. It is then necessary for someone to determine whether or not the computed concentrations are valid. Obviously, if a value is determined to be invalid, it must be deleted or changed in the master data file.

5.0 MAINTENANCE

5.1 Role of Maintenance

Maintenance requirements for automatic monitoring equipment can be divided into two areas: routine (preventive), and nonroutine. Routine maintenance procedures are necessary to provide optimum operational performance and minimum instrument downtime. Nonroutine maintenance is required as needed to rectify instrument failures. A constant failure rate will be established as a result of routine maintenance. Proper preventive maintenance will decrease this failure rate to its minimal level.

5.2 Routine Maintenance of Automatic Monitors

The magnitude of specific maintenance requirements will be a function of each individual monitor. Factors affecting this demand are engineering design and the reliability of components employed within the system. Initially, careful consideration of maintenance requirements should be made from the manufacturer's instrument manual. These requirements should be incorporated into the operational log in the form of periodic checks. An example of these maintenance requirements for a conductimetric SO_2 monitor has been presented in section 4.0. In addition to the periodic checks contained in the operational log, detailed procedures for use by the instrument technician should be developed. These procedures will insure continuity in the performance of all levels of maintenance requirement.

Several years ago, maintenance procedures were developed by the Air and Industrial Hygiene Laboratory of the California State Department of Public Health. California's Statewide Cooperative Air Monitoring Network (SCAM) employs these procedures to assist its personnel in the operation, calibration, and maintenance of its automatic equipment, which is primarily photometric monitors. These procedures provide the inexperienced as well as the more experienced personnel with an organized approach to the identification and rectification of chemical, mechanical, and electronic problems. These published[35] procedures can serve as an example of the type of approach to employ while developing routine and nonroutine maintenance procedures for use with other types of automatic monitors.

5.3 Nonroutine Maintenance of Automatic Monitors

Equipment failures will require immediate remedial actions. The course of these actions will vary with the cause of the failure. One method of effective nonroutine maintenance is to first determine the source of failure by means of diagnostic troubleshooting procedures. In most instances the best available source of information pertaining to corrective measures will be found in the manufacturer's instrument manual. The frequency, source, and corrective measures necessary for rectifying the failure should be recorded in the operational log. Periodically, a review of these failures will provide an insight into new areas in which routine and preventive maintenance schedules should be developed. Thus, the frequency of nonroutine maintenance will be reduced.

5.3.1 Troubleshooting

Failures requiring nonroutine maintenance often become obvious to the instrument technician upon visual inspection of the malfunctioning instrument. In these cases the need for troubleshooting procedures for the identification of problem areas is not necessary. When visual inspection does not lead to an obvious solution, a diagnostic troubleshooting approach may be employed to locate the problem area. In many cases detailed troubleshooting guides are provided by the manufacturer. In other cases it will be difficult to develop detailed guides without a complete knowledge of the physical, chemical, and electronic parameters of the system. For this reason, complex nonroutine maintenance requirements should be reserved for the manufacturer's staff of qualified service engineers.

Often the failure, at first observation, appears to be complex or of unknown origin. To avoid unnecessary service calls, a simple troubleshooting guide can be developed and employed by an instrument technician which will aid him in determining the extent of the instrument malfunction. The development of this troubleshooting guide can best be accomplished if each component or subsystem of the monitor is considered separately. Several subsystems are common to most monitors, e.g.:

(a) Electronic Subsystems--The electronic system can be subdivided into three areas: the detection, amplification, and display of the electronic signal. Electronic checks for each of these subsystems are necessary to define the operational performance of the total electronic system. In this regard, it is essential to maintain a reference record of prior electronic measurements, at several vital points within the various subsystems, under normal operational conditions. To insure that the values are representative, they should be made after dynamic calibration of the monitor. Thus the electronic system troubleshooting guide would consist of a table of reference points relating to the schematic diagram of the monitor, and corresponding to the electronic reference values obtained. Subsequent comparison of the "standard" data obtained as a result of these measurements and measurements made during troubleshooting efforts would enable rapid identification of faulty components and subsystems.

(b) Mechanical Subsystems--Most automatic monitoring equipment has a limited number of mechanical components. Therefore, troubleshooting this subsystem is usually limited to such items as switches, valves, pumps, and the like. One simple approach to troubleshooting this system is to observe the mechanical functions of the various suspect components for normal operation. Also, substitution of new components often leads to identification of problem areas through the process of elimination. Thus there are no real guidelines necessary in this particular area. However, tests such as pressure and flow measurements can be made to verify the normal operation of these components.

(c) Chemical Subsystems--Automatic monitors employing reagents which include gases, liquids, and solids have an inherent source of malfunction. Reagents are another variable within the system which are subject to deterioration, depletion, and contamination. Two ways of troubleshooting this system are practical. The reagents can be directly replaced or, in some cases, tested for proper composition or quality by measuring a property such as conductivity or optical density. A prior knowledge of the reagents physical and chemical parameters is required. This information, in some cases, can be obtained from published literature on the specific method. Often it is necessary to develop it in-house. This can be accomplished by making the appropriate measurements, e.g., optical density, conductivity, purity tests, etc., on reagents from working systems. This information should then be entered into the troubleshooting guide for future reference.

(d) Optical Subsystems--Troubleshooting of many automatic monitors employing optical measurement principles can be accomplished by inserting apertures of various size into the light path to decrease the signal to the detector. Caution should be exercised while employing this test to avoid misalignment of the optical system.

As a result of the use of these subsystems troubleshooting guides, the instrument technician will be in a better position to schedule the proper amount of maintenance necessary, and provide in-house capabilities in these areas. If the malfunction is found to be beyond the in-house maintenance capabilities, an expert service engineer should be called.

5.4 Maintenance of Remote Stations

Maintenance requirements for the physical care of the remote station should not be overlooked. Schedules for general housekeeping duties should be prepared. This schedule should include, as a minimum, the following items:

- Interior housekeeping--Cleaning of floor, walls, windows, benches, etc.

- Physical maintenance of monitors--Cleaning of monitors, sample lines, and sample manifold.
- Maintenance of heating and cooling systems--Change filters and oil motors as prescribed by the manufacture.
- Exterior maintenance--Lawn care and snow removal.

6.0 CHARACTERISTICS OF AIR MONITORING EQUIPMENT

To describe physical and performance characteristics of air monitoring equipment, various special terms are used. However, the terms used are not always consistent. Currently, many different terms are used synonymously, whereas at other times, the same term may have connoted different meanings. Thus, the terms listed in the preceding sections of this manual and other commonly used performance terms require general definition to avoid confusion.

In an attempt to generally define these terms, definitions from technical publications and dictionaries were utilized. Many terms were redefined and new definitions were introduced. In this effort, there was considerable consultation with members of APCO's Standards Advisory Committee and other colleagues. Also, in addition to terms directly related to these characteristics, other general descriptions of air monitoring instrumentation are included in Section 6.4.

6.1 Physical Characteristics

Pollutant: The specific chemical or physical substance that the instrument is designed to detect.

Manufacturer: The name of the company or organization which assembled, fabricated, or otherwise produced the instrument.

Model: An identifying name or alphanumeric code other than the tradename assigned by the manufacturer to identify the instrument.

Tradename: The name used by the manufacturer to identify a particular instrument or series of instruments.

Vendors: The independent dealers or distributors of the instrument, instrument supplies, parts, and service.

Size: The overall dimensions of height, width, and depth of the instrument. Basic instrument usually includes the sampling, analysis, and detection systems and may consist of more than one unit. Components such as data display and/or recording systems, pumps, reagent containers, etc., are included even though these may be external to the instrument cabinet. It does not include items listed by the manufacturer as auxilary or accessory.

Space Requirements: The dimensions of height, width and depth required for installation, operation and maintenance of an instrument. It includes space needed by all auxilary items and equipment and includes swinging space for cabinet access doors and panels.

Auxilary Equipment: The identification and specifications of items designed for but not required for the analyzer to produce air quality data.

6.2 Measurement Principles

Sample Transfer Devices: Apparatus that are used to bring gases, vapors, fumes, and particulate matter into intimate contact with a liquid or solid reaction medium, or to an enclosure where a physical measurement is made. These include various kinds of absorbing tubes, columns (wet or dry), and flasks, and selectively permeable membranes (see glossary for terms and definitions).

Flow Measuring and Metering Devices: Apparatus used to measure and meter rate of fluid flow. Two main classes are flowrate meters and quantity (volume) meters.

The first type is represented by area or mass methods (rotameters); differential pressure methods (impact and pitot tubes, orifices, nozzles and venturi meters); caloric methods (hot-wire catharometer); and impulse methods (vane and cup anemometers).

The second type is represented by wet gas meters; dry gas meters; bellows or diaphram meters; cycloidal, rotary disk and rotary pistons. Wet and dry gas meters measure total volume only. The average volume rate may be calculated when the time interval is known (see glossary for definition of specific flow measuring devices).

Detection Methods: Those techniques which quantitatively detect the presence of a pollutant through direct physical measurement or through indirect measurement of a reaction product, and include the following: colorimetry, conductimetry, amperometry, potentiometry, and several physical methods such as: absorption, emission, ultraviolet, infrared, and correlation spectroscopies; mass spectrometry; and nondispersive infrared absorption and flame photometry. Inherent in most detection devices is a reference system in which the instrument output is compared to a known quantity such as background voltage or current, or color intensity of a blank solution (see glossary for terms and definitions).

Signal Presentation Devices: Those components such as ammeters, voltmeters, various types of recorders, digital readout units, computers, and other data acquisition systems that are used to convert the analyzer output (the signal from the detection device) to a usable form. The analyzer output is usually in the form of a voltage, a current, or power. The output is related to the input by either a linear or nonlinear function. The nonlinear function is usually an exponential one but occasionally an undefined, nonlinear function is used (see glossary for terms and definitions).

6.3 Performance Characteristics

The emphasis of the following characteristics is on the performance of the overall analyzer system and not on the performance of individual components.

6.3.1 Environmental Requirements

Temperature Operating Range: The range of ambient temperature over which the instrument will meet stated performance specifications.

Humidity Operating Range: The range of ambient relative humidity over which the instrument will meet stated performance specifications.

Vibration Operating Range: The range, in type and intensity, of mechanical vibration over which the instrument will meet stated performance specifications. The emphasis is on analyzers designed for portability in field use in motor vehicles and aircraft.

6.3.2 Measurement Output

Accuracy: The difference between a measured value and the true value which is known or assumed usually expressed as ± % of full scale.

Full Scale: The maximum measuring limit for a given range.

Interference: An undesired positive or negative output caused by a substance other than the one being measured.

Interference Equivalent: The portion of indicated concentration due to the total interference, commonly found in ambient air.

Linearity: The maximum deviation between an actual instrument reading and the reading predicted by a straight line drawn between the upper and lower calibration points.

Minimum Detectable Change: The smallest change in inlet concentration which can be detected distinguishable from instrument noise for outputs at mid-scale and 80 percent of full scale. The magnitude of change in inlet concentration required may differ with pollutant concentration and may also be different for positive and negative displacements.

Minimum Detectable Sensitivity: The smallest amount of input concentration which can be detected as the concentration approaches zero.

Noise: Spontaneous deviations from a mean output not caused by input concentration changes.

Operational Period: The period of time over which the instrument can be expected to operate unattended within specifications.

Precision: The degree of agreement between repeated measurements of the same concentration (which shall be the midpoint of the stated range) expressed as the average deviation of the single results from the mean.

Range: The minimum and maximum measurement limits.

6.3.3 Dynamic Response

Zero Drift: The change in instrument output over a stated period of unadjusted continuous operation when the input concentration is zero.

Span Drift: The change in instrument output over a stated period of unadjusted continuous operation when the input concentration is a stated upscale value.

Lag Time: (initial response time, t_i): The time interval from a step change in the inlet concentration at the instrument inlet to the first corresponding change in the instrument output distinguishable from instrument noise.

Rise Time 90 Percent: The interval between the initial response time and the time to 90 percent response after a step increase in inlet concentration.

Time to 90 Percent Response (t_{90}): The time interval from a step change in the input concentration at the instrument inlet to a reading of 90 percent of the ultimate recorded concentration.

Fall Time 90 Percent: The interval between the initial response time and the time to 90 percent response (t_{90}) after a step decrease in the inlet concentration.

Response Time Constant (t_c): The time required for the instrument output to go from zero--to full scale--to zero in response to a full-scale square-wave change in inlet concentration of the shortest duration which will indicate full scale. It is represented as $t_c = t_r + t_f$, and is a measure of the instrument's ability to resolve pulsed inputs of pollutants.

Warmup Time: The elapsed time necessary after startup for the instrument to meet stated performance specifications when the instrument has been shut down for at least 24 hours. A short warmup period is essential for instruments designed for portable field use.

6.4 GLOSSARY

Absorber (contactor, contact column, scrubber): A device for bringing gases, vapors, fumes, and particulate matter into intimate contact with an absorbing medium. An absorber design with minimum surface area and turbulence consistent with complete absorption of interferents. The following seven terms apply to the absorber:

(a) Bubbler: An absorber in which the sample gas stream is broken up into many small bubbles by being forced through multiple openings or a fritted glass tip below the surface of the absorbing solution. Bubblers may be tall or short depending on the efficiency of the absorption process.

(b) Helical Column: A column made from glass tubing which has been coiled around a cylindrical form with one or more turns and mounted with its axis vertical. Gas-liquid flow is concurrent and may be up or down the column. High wetted-surface area is achieved by selecting a tube diameter sufficiently small to insure that the surface tension of the solution will cause the entire interior surface to become wetted.

(c) Helix Insert Column: A high-surface-area type absorber composed of a narrow tube with a glass or wire helix placed axially and in contact with the interior column wall. Liquid usually passes down the column in a thin film over the helix. Gas flow may be concurrent or countercurrent. The helix may also be wrapped around a center support with the gas-liquid mixture passing between the column wall and the center support.

(d) Impinger jet: Sample air blown or aspirated onto or below the surface of the absorbing medium. Absorption is increased by both high surface area and by turbulence.

(e) Mechanical Scrubber: A device designed to bring the gas and absorbing medium into intimate contact by mechanical agitation. Absorption is increased by both high surface area and by turbulence.

(f) Packed Column: A high-surface-area type absorber, usually a tubular column loosely filled with an inert media such as Raschig rings, helices, crushed or sintered glass, beads, or other materials of various shapes. Gas and liquid flow may be concurrent or countercurrent with absorption taking place on wetted surfaces. A single or a series of sintered glass plates through which the gas-liquid mixture is passed may be used in place of inert packing.

(g) Spray jet: Absorbing solution forced through an orifice at high velocity and impacted on the interior surface of the absorbing chamber. Gas is absorbed through mixing and turbulence created by the impaction. Kinetic energy is imparted to the liquid by hydraulic pressure, sample air pressure, or by aspiration caused by the air flow into the chamber.

Absorption: A reaction in which gas molecules are transferred to a liquid phase by diffusion. The driving force is a function of the concentration differential at the gas-liquid interface. The process is favored by high interfacial areas, turbulence, and high diffusion coefficients. Absorbents should have high solubility and react irreversibly with the absorbed gas.

Absorption Spectroscopy (ultraviolet, visible, infrared, and microwave): A physical means of detecting and measuring the presence of compounds by the selective absorption of electromagnetic radiation which is passed through a region containing the compounds.

Amperometry (frequently called coulometry; coulometry suggests an instrument output the same as that which can be predicted theoretically): The reaction and measurement of a pollutant with a chemical solution which causes an electrical current proportional to pollutant concentration.

Analysis, Automated: A process in which samples are detected and analyzed automatically by a device.

Analysis, Semi-automated: An automated process in which one or more steps in the sample collection, detection, and analysis procedure is performed manually.

Anemometer: An instrument for measuring and indicating the speed of the wind.

Calibrating Solution: A solution, containing a known amount of a substance having an effect equivalent to a pollutant concentration, that is passed through the detection component during the static calibration of an analyzer.

Calibration, Dynamic: A calibration of the complete instrument by means of sampling either a gas of known concentration or an artificial atmosphere containing a pollutant of known concentration.

Calibration, Static: A performance test of the detection and signal presentation components accomplished by using an artificial stimulus such as standard calibrating solutions, resistors, screens, optical filters, electrical signals, etc., which has an effect equivalent to pollutant concentrations.

Collection Efficiency: The amount of substance absorbed or detected divided by the amount sampled.

Colorimetry: The measurement of a color change caused by the reaction between a pollutant and a reagent solution whose color intensity is proportional to pollutant concentration.

Conductimetry: The measurement of a conductance change between two inert electrodes placed in a reagent solution whose electrical conductivity has been changed by the absorption of a pollutant.

Correlation Spectrometry: A method of making qualitative and quantitative measurements upon a gas, in which an absorption spectra is cross-correlated in real time against the spectral replica of the species sought.

Dead Band: The range through which the input to a system may be varied without initiating an output response. (Commonly applied to servo-systems such as recorders but is applicable to continuous analyzers as well.

Detector (sensor, transducer): A device which detects the presence of an entity of interest and indicates its magnitude as the deviation from a reference and converts these indications into a signal (e.g., photometer, infrared bolometer, flame-ionization detector, etc.).

Dry-gas Meter (bellows or diaphram meter): A device which measures total volume of a gas passed through it without the use of volatile liquids.

Emission Spectroscopy: The detection and analysis of substances by measuring characteristic spectra emitted by the substance when excited by heat, radiation, electrical discharge, or other stimuli.

Flame Photometry: The detection and analysis of substances by measuring the characteristic spectra emitted by excitation in a flame. Narrow-band-pass optical filters may be used to isolate a characteristic emission line when measuring a single substance.

Fluorimetry: The detection and analysis of substances by measurement of characteristic electromagnetic radiation (usually visible light) emitted by the substance during exposure to radiation of higher frequency (usually ultraviolet light).

Impact and Pitot Tubes: Devices used to measure the velocity of fluid flow by measuring the difference between perpendicular pressures (on-axis and off-axis) at various points in the flow stream.

Instrument Inlet: The opening at the instrument through which the sample enters the analyzer, excluding all external sample lines, probes, and manifolds.

Ionization Detector (flame and radiogenic): A very sensitive device capable of detecting the presence of pollutant ions produced by passage through a flame or a region of radioactive emissions. The flame ionization detector is specific for combustible organic compounds; the radiogenic detector is relatively nonspecific.

Luminescence: An emission of light that occurs at low temperatures and that is not incandescence. It is often produced by physiological processes, chemical action, friction, or by electrical action.

Noise: The spontaneous, short-term variations in response occurring periodically or randomly at any concentration but not caused by variations in pollutant concentration.

Nozzle: An orifice in the shape of a tube designed for measuring fluid flow. The tube is so shaped as to impart velocity to a fluid stream to produce pressure-flow characteristics which can be translated to flow rate.

Orifice: An opening through which a fluid can pass. The orifice is so shaped as to provide pressure-flow characteristics which can be translated to flow rate. At fluid flow rates approaching sonic velocities, the orifice provides flow characteristics useful for controlling flow.

Portability: A qualitative term, used to describe the relative ease with which an analyzer may be moved about, which is divided roughly into two classifications--portable and stationary. All analyzers can be used as stationary units but portable analyzers must be designed to withstand the rigors of vibration and acceleration found in transportation, must be lightweight, and must have short warmup times.

Potentiometry: The measurement of the reaction of a pollutant with a liquid reagent in an electrochemical (oxidation-reduction) cell using unpolarized electrodes. The reaction produces an electromotive force proportional to the pollutant concentration.

Primary Standard: A substance with a known property which can be defined, calculated, or measured, and which is readily reproducible. The standard may be traceable to the National Bureau of Standards or other accepted standards organization.

Rotameter (variable area flowmeter): A flow-measuring device that operates at constant pressure and consists of a weight or float in a tapered tube. As the flow rate increases, the float moves to a region of larger area and seeks a new position of equilibrium in the tapered tube, the position being related to flowrate.

Sample: A representative portion or specimen of an entity presented for inspection.

Sample, Grab: A single sample rapidly collected at any specific period in time. Gaseous samples are usually collected in a container, absorbed on a solid or in a solution over a time period not less than one minute.

Sample, Integrated: The sum of a series of small samples or a continuous flow of sample collected over a finite time period (from minutes to hours) so as to create a large average sample. An integrated sample is often stored for a period of time before analysis although losses may occur.

Sample, Automated: A process in which a sample is collected automatically by a programmed device. The sample is not detected or analyzed during collection.

Sampling, Continuous: A process in which samples are collected continuously at a known rate.

Sampling, Discontinuous: A process in which a single integrated sample is collected over a discontinuous, predetermined time interval or until a predetermined volume is collected. The ratio of on-time versus off-time is stated.

Sampling, Random: A process in which grab or integrated samples are collected at random intervals.

Sampling, Sequential: A process in which a series of individual grab or integrated samples are collected one after the other at regular predetermined intervals.

Sampling and Analysis, Automated: A process in which a sample is collected, detected, and analyzed automatically by a device.

Secondary Standard: A substance having a property which is calibrated against a primary standard to a known accuracy.

Selectively Permeable Membrane: A device which allows a pollutant or class of pollutants to selectively diffuse through a gas barrier to react with a reagent.

Signal-to-noise Ratio: The ratio of the magnitude of the signal to that of the noise. A ratio of two is usually the smallest value that can be used with confidence.

Standardization: Adjustment of the instrument variables to make the output conform to predetermined or convenient values.

Stock Solution: A solution containing a substance which has an effect equivalent to pollutant concentrations, and which is standardized against a primary or secondary standard.

Venturi Tube: A specially shaped tube for measuring the rate of fluid flow. The tube is so shaped as to impart velocity to a fluid stream, but is followed by a gradually expanding cone which minimizes frictional loss of kinetic energy, and which at the same time produces pressure-flow characteristics which can be translated to flow rate.

Wet-gas Meter: A volumetric flow measuring device that measures the total gas volume by entrapping the gas in inverted cups or vanes under a liquid. The buoyancy of the gas causes a rotation of the cups or vanes that is proportional to the volume which is indicated on a precalibrated meter.

Working Solution: A solution prepared from a stock solution and used for preparing a range of calibrating solutions.

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Appendix A

Compilation of Monitors

APPENDIX A

COMPILATION OF MONITORS

Manufacturer and address	Pollutant measured	Measurement principle	Approx. cost $	Remarks
Beckman Instrument Co. 2500 Harbor Blvd. Fullerton, Calif. 92634	Total hydrocarbon	Flame ionization	2,000	Without recorder
Bendix Corp. Environmental Science Div. 1400 Taylor Ave. Baltimore, Md. 21204	do	do	1,200 to 7,800	do
Davis Instrument Co. Route US 29 North Box 751 Charlottesville, Va. 22902	do	do	2,700	do
Mine Safety Appliances Co. 201 N. Braddock Ave. Pittsburgh, Pa. 15208	do	do	2,000	do
Beckman Instrument Co. 2500 Harbor Blvd. Fullerton, Calif. 92634	Total hydrocarbon, methane, & carbon monoxide	Gas chromatographic	10,000	New instrument with recorder
Mine Safety Appliances Co. 201 N. Braddock Ave. Pittsburgh, Pa. 15208	do	do	10,000	do
Tracor, Inc. 6500 Tracor Lane Austin, Texas 78721	do	do	10,500	do
Union Carbide Corp. 5 New Street White Plains, N.Y. 10601	do	do	10,000	do

Compilation of Monitors (continued)

Manufacturer and address	Pollutant measured	Measurement principle	Approx. cost $	Remarks
Beckman Instrument Co. 2500 Harbor Blvd. Fullerton, Calif. 92634	Carbon monoxide	Infrared	3,500	Without recorder
Bendix Corp. Environmental Science Div. 1400 Taylor Ave. Baltimore, Md. 21204	do	do	2,600 to 3,200	do
Intertech Corp. 262 Alexander Street Princeton, N.J. 08540	do	do	3,300	do
Mine Safety Appliances Co. 201 N. Braddock Ave. Pittsburgh, Pa. 15208	do	do	1,700 to 2,700	do
Atlas Electric Devices Co. 4114 N. Ravenswood Ave. Chicago, Illinois 60613	Sulfur dioxide	Coulometric	4,400	Includes recorder with automatic zero or span
Barton Instrument Corp. Div. of ITT 580 Monterey Pass Road Monterey Park, Calif. 91754	do	do	5,000	Includes recorder
Beckman Instrument Co. 2500 Harbor Blvd. Fullerton, Calif. 92634	do	do	2,600	Without recorder
Beckman Instrument Co. 2500 Harbor Blvd. Fullerton, Calif. 92634	Sulfur dioxide & hydrogen sulfide	Flame photometric gas C	-	New instrument without recorder
Beckman Instrument Co. 2500 Harbor Blvd. Fullerton, Calif. 92634	Sulfur dioxide	Conductimetric	3,560	Without recorders

Compilation of Monitors (continued)

Manufacturer and address	Pollutant measured	Measurement principle	Approx. cost $	Remarks
Bendix Corp. Environmental Science Div. 1400 Taylor Ave. Baltimore, Md. 21204	Sulfur dioxide	Flame photometric	3,700 to 3,950	With recorder
Calibrated Instruments 17 West 60th Street New York, N.Y. 10023	do	Conductimetric	4,000	Equipped with printout device
Davis Instrument Co. Route US 29 North Box 751 Charlottesville, Va. 22902	do	do	2,300	Without recorder
Dynasciences 9601 Canoga Ave. Chatsworth, Calif. 91311	do	Coulometric	2,300	New instrument electrochemical (dry) without recorder
Enviro Metrics, Inc. 13311 Beach Ave. Marina Del Rey, Calif. 90291	do	Coulometric (Fairstor)	1,900	do
Instrument Development Co. 1916 Newton Square West Reston, Va. 22070	do	Conductimetric	2,780	With recorder
Instrument Development Co. 1916 Newton Square West Reston, Va. 22070	do	Conductivity	3,800	With recorder & gas test meter
Intertech Corp. 262 Alexander Street Princeton, N.J. 08540	do	Coulometric	3,300	New instrument electrochemical cell (dry) without recorder

Compilation of Monitors (continued)

Manufacturer and address	Pollutant measured	Measurement principle	Approx. cost $	Remarks
Intertech Corp. 262 Alexander Street Princeton, N.J. 08540	Hydrogen sulfide	Colorimetric	3,300	New instrument without recorder
Kimoto Electric Corp. Ltd. 42 Funahashi-cho Tennoji-Ku Osaka, Japan	Sulfur dioxide	Conductimetric	2,900	With recorder (batch system)
Leeds & Northrup Sumneytown Pike North Wales, Pa. 19454	do	Conductimetric	4,900	Without recorder
Litton Systems, Inc. 3841 E. Santa Rosa Road Camarillo, Calif. 93010	do	Colorimetric	5,000	do
Meloy Laboratories 6631 Iron Place Springfield, Va. 22151	Total sulfur	Flame photometric	3,300	do
Monitor Labs, Inc. 10451 Roselle San Diego, Calif. 92121	Sulfur dioxide	Colorimetric	1,500	do
Monitor Labs, Inc. 10451 Roselle San Diego, Calif. 92121	do	Conductimetric	1,500	do
Philips, Inc. Eindhoven, Netherlands	do	Coulometric	5,000	do
Pollution Monitors, Inc. 722 West Fullerton Ave. Chicago, Ill. 60614	do	Colorimetric	2,000	New instrument without recorder
Precision Scientific 3737 West Cortland Street Chicago, Ill. 60647	do	Colorimetric	2,000	do
Process Analyzers, Inc. 6400 Southwest Freeway Houston, Texas 77036	do	Coulometric	4,000	Without recorder

Compilation of Monitors (continued)

Manufacturer and address	Pollutant measured	Measurement principle	Approx. cost $	Remarks
Scientific Industries 15 Park Street Springfield, Mass. 01103	Sulfur dioxide	Conductimetric	2,000	With recorder
Technicon Controls, Inc. Tarrytown, N.Y. 10502	do	Colorimetric	5,240	do
Tracor, Inc. 6500 Tracor Lane Austin, Texas 78721	Sulfur dioxide & hydrogen sulfide	Flame photometric gas C	5,700	New instrument without recorder must include auto-function; price: $3,200
Wilkens-Anderson Co. 4525 West Division Street Chicago, Ill. 60651	Sulfur dioxide	Colorimetric	3,000	With recorder
Atlas Electric Devices Co. 4114 N. Ravenswood Ave. Chicago, Ill. 60613	Nitrogen dioxide	Colorimetric	2,830	With recorder
Beckman Instrument Co. 2500 Harbor Blvd. Fullerton, Calif. 92634	do	do	3,560	Without recorder
Beckman Instrument Co. 2500 Harbor Blvd. Fullerton, Calif. 92634	do	Coulometric	3,200	New instrument without recorder
Dynasciences 9601 Canoga Ave. Chatsworth, Calif. 91311	do	do	2,300	New instrument electrochemical transducer without recorder

Compilation of Monitors (continued)

Manufacturer and address	Pollutant measured	Measurement principle	Approx. cost $	Remarks
Enviro Metrics, Inc. 13311 Beach Ave. Marina Del Rey, Calif. 90291	Nitrogen dioxide	Coulometric	1,900	New instrument electrochemical (dry) without recorder
Intertech Corp. 262 Alexander Street Princeton, N.J. 08540	do	Coulometric	3,300	New instrument without recorder
Litton Systems, Inc. 3841 E. Santa Rosa Road Camarillo, Calif. 93010	do	Colorimetric	5,000	Without recorder
Pollution Monitors 722 West Fullerton Ave. Chicago, Ill. 60614	do	do	1,800	New instrument without recorder
Precision Scientific 3737 West Cortland Street Chicago, Ill. 60647	do	do	1,800	Without recorder
Scientific Industries 150 Herricks Road Mineola, N.Y. 01103	do	do	2,000	With recorder
Technicon Controls, Inc. Tarrytown, N.Y. 10591	do	do	5,240	do
Wilkens-Anderson Co. 4525 West Division Street Chicago, Ill. 60651	Nitrogen dioxide	Colorimetric	2,800	Without recorder
Atlas Electric Devices Co. 4114 N. Ravenswood Ave. Chicago, Ill. 60613	Oxidant (O_3)	Coulometric	3,300	With recorder
Beckman Instrument Co. 2500 Harbor Blvd. Fullerton, Calif. 92634	do	Colorimetric	3,600	Without recorder

Compilation of Monitors (continued)

Manufacturer and address	Pollutant measured	Measurement principle	Approx. cost $	Remarks
Beckman Instrument Co. 2500 Harbor Blvd. Fullerton, Calif. 92634	Oxidant (O_3)	Coulometric	3,000	New instrument without recorder
Bendix Corp. Environmental Science Div. 1400 Taylor Ave. Baltimore, Md. 21204	do	Gas phase chemiluminescent	4,700 to 4,950	Without recorder
Dasibi Corp. 3223 North Verdugo Glendale, Calif. 91208	do	UV absorption	4,000	do
Intertech Corp. 262 Alexander Street Princeton, N.J. 08540	do	Coulometric	3,300	New instrument without recorder
Litton Systems, Inc. 3841 E. Santa Rosa Road Camarillo, Calif. 93010	do	Colorimetric	5,000	Without recorder
Mast Development Co. 2212 East 12th Street Davenport, Iowa 52803	Oxidant	Coulometric	1,100	Without recorder
Rem, Inc. 3107 Pico Blvd. Santa Monica, Calif. 90405	do	Gas phase chemiluminescent	3,500	New instrument without recorder
Technicon Tarrytown, N.Y. 10591	do	Colorimetric	5,240	With recorder
Gelman Instrument Co. P. O. Box 1448 Ann Arbor, Mich. 48106	Soiling	Tape Sampler	1,000	With reader & recorder
Instrument Development Co. 1916 Newton Square So. Reston, Va. 22070	do	Tape Sampler	400	Without reader & recorder

Compilation of Monitors (continued)

Manufacturer and address	Pollutant measured	Measurement principle	Approx. cost $	Remarks
Research Appliance Co. Route 8 & Craighead Road Allison Park, Pa 15101	Soiling	Tape Sampler	750	With reader & recorder
Gelman Instrument Co. P. O. Box 1448 600 S. Wagner Street Ann Arbor, Mich. 48106	Suspended particulates	Filtration	500	With flow recorder
General Metal Works Air Sampling Equipment Cleves, Ohio 45002	do	do	350	do
Meteorology Research, Inc. P. O. Box 637 Altadena, Calif. 91001	do	Integrating nephelometer	5,300	With recorder
Research Appliance Co. Route 8 & Craighead Road Allison Park, Pa. 15101	do	Filtration	350	With flow recorder
The Staplex Co. 774 5th Ave. Brooklyn, N.Y. 11232	do	do	150	Without flow recorder

Appendix B

National Primary and Secondary Ambient Air Quality Standards

Appendix B

National Primary and Secondary Ambient Air Quality Standards

On April 30, 1971, Administrator William D. Ruckelshaus of the Environmental Protection Agency established National Primary and Secondary Ambient Air Quality Standards for six common classes of air pollution: sulfur dioxide, particulate matter, carbon monoxide, photochemical oxidants, nitrogen dioxide, and hydrocarbons. As published in the Federal Register, these standards are designed to protect public health and welfare by setting limits on levels of pollution in the air. They apply to all areas of the United States.

The Environmental Protection Agency has authority, under amendments to the Clean Air Act (1970), to set national primary and secondary air quality standards for those air pollutants for which air quality criteria are published. Primary standards are designed to protect human health. Secondary standards are designed to protect against effects on soil, water, vegetation, minerals, animals, weather, visibility, personal comfort and well-being. The criteria describe the relationship between levels of pollution and the associated effects on health and welfare. Criteria for sulfur oxides, particulate matter, carbon monoxide, oxidants, hydrocarbons, and nitrogen oxides were previously published by the Federal Government.

With each set of criteria, the Federal Government has published a control technology document.

The primary and secondary standards for the six common classes of pollution follow:

Sulfur dioxide

Primary standards

° 80 micrograms per cubic meter (0.03 ppm) annual arithmetic mean

° 365 micrograms per cubic meter (0.14 ppm) maximum 24-hour concentration not to be exceeded more than once per year.

Secondary standards

° 60 micrograms per cubic meter (0.02 ppm) annual arithmetic mean

° 260 micrograms per cubic meter (0.10 ppm) maximum 24-hour concentration not to be exceeded more than once per year.

° 1,300 micrograms per cubic meter (0.5 ppm) maximum 3-hour concentration not to be exceeded more than once per year.

Sulfur oxides in the air come primarily from the combustion of sulfur-containing fossil fuels. Their presence has been associated with increased incidence of respiratory diseases, increased death rates, and property damage.

Particulate matter

Primary standards

° 75 micrograms per cubic meter, annual geometric mean

° 260 micrograms per cubic meter, maximum 24-hour concentration not to be exceeded more than once per year.

Secondary standards

° 60 micrograms per cubic meter, annual geometric mean

° 150 micrograms per cubic meter, maximum 24-hour concentration not to be exceeded more than once per year.

Particulate matter, solid or liquid, may originate naturally or as a result of industrial processes and other human activities. By itself or in association with other pollutants, it may injure the lungs or cause adverse effects elsewhere in the body.

Particulates also reduce visibility and contribute to property damage and soiling.

Carbon monoxide

Primary and secondary standards

- 10 milligrams per cubic meter (9 ppm), maximum 8-hour concentration not to be exceeded more than once per year.
- 40 milligrams per cubic meter (35 ppm), maximum 1-hour concentration not to be exceeded more than once per year.

Carbon monoxide is a product of incomplete burning of carbon-containing fuels, and of some industrial processes. It decreases the oxygen-carrying ability of the blood and, at levels often found in city air, may impair mental processes.

Photochemical oxidants

Primary and secondary standards

- 160 micrograms per cubic meter (0.08 ppm), maximum 1-hour concentration not to be exceeded more than once per year. Measurement to be corrected for interferences due to nitrogen oxides and sulfur dioxide.

Photochemical oxidants are produced in the atmosphere when reactive organic substances, chiefly hydrocarbons, and nitrogen oxides are exposed to sunlight. They irritate mucous membranes, reduce resistance to respiratory infection, damage plants, and contribute to deterioration of materials.

Nitrogen oxides

Primary and secondary standards

- 100 micrograms per cubic meter (0.05 ppm), annual arithmetic mean

Nitrogen oxides usually originate in high-temperature combustion processes. The presence of nitrogen dioxide in ambient air has been associated with a variety of respiratory diseases.

Nitrogen dioxide is essential to the production of photochemical smog.

Hydrocarbons

Primary and secondary standards

° 160 micrograms per cubic meter (0.24 ppm), maximum 3-hour concentration (6 to 9 a.m.) not to be exceeded more than once per year. Measurement corrected for methane.

Hydrocarbons come mainly from the processing, marketing, and use of petroleum products. Some of the hydrocarbons combine with nitrogen oxides in the air to form photochemical oxidant.

Under the 1970 amendments, the States were given nine months from the date that the standards are promulgated (i.e. April 30, 1971) to submit plans for controlling the sources of pollution to meet the standards. EPA may allow a State up to 27 months to submit plans for achieving secondary standards.

Appendix C

Conversion Tables

Table C-1. CORRECTION OF OBSERVED PERMEATION RATE
TO STANDARD TEMPERATURE (25.0° C)
FOR SO_2 PERMEATION TUBES[a]

Temp °C	Correction factor[b]	Temp °C	Correction factor	Temp °C	Correction factor	Temp °C	Correction factor
10.0	0.280	12.4	0.345	14.8	0.423	17.2	0.519
10.1	0.283	12.5	0.347	14.9	0.426	17.3	0.523
10.2	0.285	12.6	0.351	15.0	0.430	17.4	0.528
10.3	0.287	12.7	0.353	15.1	0.434	17.5	0.532
10.4	0.290	12.8	0.356	15.2	0.437	17.6	0.535
10.5	0.293	12.9	0.360	15.3	0.442	17.7	0.542
10.6	0.295	13.0	0.362	15.4	0.445	17.8	0.547
10.7	0.298	13.1	0.366	15.5	0.449	17.9	0.550
10.8	0.300	13.2	0.368	15.6	0.453	18.0	0.556
10.9	0.303	13.3	0.372	15.7	0.456	18.1	0.560
11.0	0.306	13.4	0.375	15.8	0.461	18.2	0.563
11.1	0.308	13.5	0.378	15.9	0.465	18.3	0.568
11.2	0.311	13.6	0.382	16.0	0.468	18.4	0.573
11.3	0.314	13.7	0.385	16.1	0.473	18.5	0.578
11.4	0.316	13.8	0.388	16.2	0.476	18.6	0.582
11.5	0.319	13.9	0.392	16.3	0.481	18.7	0.588
11.5	0.322	14.0	0.395	16.4	0.485	18.8	0.592
11.6	0.322	14.1	0.399	16.5	0.490	18.9	0.599
11.7	0.324	14.2	0.402	16.6	0.493	19.0	0.602
11.8	0.327	14.2	0.402	16.7	0.497	19.1	0.609
11.9	0.330	14.3	0.406	16.8	0.501	19.2	0.613
12.0	0.333	14.4	0.409	16.8	0.501	19.3	0.619
12.1	0.336	14.5	0.412	16.9	0.506	19.4	0.622
12.2	0.339	14.6	0.415	17.0	0.510	19.4	0.622
12.3	0.342	14.7	0.419	17.1	0.515	19.5	0.629

[a] G. P. Scargingelli, S. A. Frey, and B. E. Saltzman. "Evaluation of Teflon Permeation Tubes for Use with Sulfur Dioxide," Am. Ind. Hygiene Assn. J., Vol. 28 (May-June 1967).

[b] Multiply by this factor.

Table C-1 (continued).

Temp °C	Correction factor	Temp °C	Correction factor	Temp °C	Correction factor	Temp °C	Correction factor
19.6	0.634	22.3	0.800	25.0	1.000	27.7	1.266
19.7	0.640	22.4	0.813	25.1	1.010	27.8	1.282
19.8	0.646	22.5	0.820	25.2	1.020	27.9	1.290
19.9	0.652	22.6	0.826	25.3	1.026	28.0	1.299
20.0	0.658	22.7	0.830	25.4	1.031	28.1	1.307
20.1	0.662	22.8	0.833	25.5	1.042	28.2	1.325
20.2	0.667	22.9	0.840	25.6	1.053	28.3	1.333
20.3	0.676	23.0	0.848	25.7	1.064	28.4	1.342
20.4	0.680	23.1	0.855	25.8	1.070	28.5	1.351
20.5	0.685	23.2	0.862	25.9	1.081	28.6	1.370
20.6	0.690	23.3	0.866	26.0	1.093	28.7	1.379
20.7	0.694	23.4	0.870	26.1	1.099	28.8	1.399
20.8	0.699	23.5	0.877	26.2	1.111	28.9	1.409
20.9	0.704	23.6	0.885	26.3	1.117	29.0	1.418
21.0	0.714	23.7	0.893	26.4	1.130	29.1	1.429
21.1	0.725	23.8	0.901	26.5	1.136	29.2	1.439
21.2	0.730	23.9	0.917	26.6	1.149	29.3	1.460
21.3	0.735	24.0	0.926	26.7	1.163	29.4	1.471
21.4	0.741	24.1	0.930	26.8	1.170	29.5	1.481
21.5	0.746	24.2	0.935	26.9	1.183	29.6	1.493
21.6	0.752	24.3	0.943	27.0	1.191	29.7	1.504
21.7	0.758	24.4	0.952	27.1	1.198	29.8	1.527
21.8	0.763	24.5	0.957	27.2	1.212	29.9	1.539
21.9	0.769	24.6	0.962	27.3	1.220	30.0	1.550
22.0	0.781	24.7	0.971	27.4	1.235		
22.1	0.787	24.8	0.976	27.5	1.242		
22.2	0.794	24.9	0.990	27.6	1.250		

Table C-2.

PERCENT TRANSMISSION (%T) AND OPTICAL DENSITY (O.D.)

EQUIVALENTS

%T	O.D.	%T	O.D.	%T	O.D.	%T	O.D.
100	0.000	75	0.125	50	0.301	25	0.602
99	0.004	74	0.131	49	0.310	24	0.620
98	0.009	73	0.137	48	0.319	23	0.638
97	0.013	72	0.143	47	0.328	22	0.658
96	0.018	71	0.149	46	0.337	21	0.678
95	0.022	70	0.155	45	0.347	20	0.699
94	0.027	69	0.161	44	0.357	19	0.721
93	0.032	68	0.168	43	0.367	18	0.745
92	0.036	67	0.174	42	0.377	17	0.770
91	0.041	66	0.181	41	0.387	16	0.796
90	0.046	65	0.187	40	0.398	15	0.824
89	0.051	64	0.194	39	0.409	14	0.850
88	0.056	63	0.201	38	0.420	13	0.886
87	0.061	62	0.208	37	0.432	12	0.921
86	0.066	61	0.215	36	0.444	11	0.959
85	0.071	60	0.222	35	0.456	10	1.000
84	0.076	59	0.229	34	0.469	9	1.046
83	0.081	58	0.237	33	0.482	8	1.097
82	0.086	57	0.244	32	0.495	7	1.155
81	0.092	56	0.252	31	0.509	6	1.222
80	0.097	55	0.260	30	0.523	5	1.301
79	0.102	54	0.268	29	0.538	4	1.398
78	0.108	53	0.276	28	0.552	3	1.523
77	0.114	52	0.284	27	0.569	2	1.699
76	0.119	51	0.292	26	0.585	1	2.000

Table C-3.

CONVERSION FACTORS FOR GAS-VAPOR CONCENTRATIONS--

FOR CONVERTING ppm TO $\mu g/m^3$

Gas	Chemical symbol	Molecular weight	Factor[a]
Nitric oxide	NO	30.01	1226
Nitrogen dioxide	NO_2	46.01	1880
Sulfur dioxide	SO_2	64.06	2618
Ozone[b]	O_3	48.00	1961
Methane[c]	CH_4	16.04	655
Carbon monoxide	CO	28.01	1144
Formaldehyde	HCHO	30.03	1227
Carbon dioxide	CO_2	44.00	1798
Sulfur trioxide	SO_3	80.06	3272
Ammonia	NH_4	17.03	696

[a] Each factor represents the concentration in $\mu g/m^3$ equivalent to 1 ppm by volume. The figures were generated for 25° C 760 mm Hg.

[b] Total oxidant is reported as ozone.

[c] Total hydrocarbon is reported according to calibration used, normally in methane equivalents.

Table C-4. CONVERSION FACTORS--LENGTH

Desired Units Given Units	Inch	Foot	Yard	Mile (Statute)	Micro-meter (micron)	Milli-meter	Centi-meter	Meter	Kilo-meter
Inch	1	83.33 x 10^{-3}	27.778 x 10^{-3}	1.578 x 10^{-5}	2.54 x 10^{4}	25.4	2.54	2.54 x 10^{-2}	2.54 x 10^{-5}
Foot	12	1	.3333	1.894 x 10^{-4}	30.48 x 10^{4}	304.8	30.48	30.48 x 10^{-2}	30.48 x 10^{-5}
Yard	36	3	1	5.682 x 10^{-4}	91.44 x 10^{4}	914.4	91.44	91.44 x 10^{-2}	91.44 x 10^{-5}
Mile (Statute)	6.3360 x 10^{4}	5280	1760	1	1.6094 x 10^{9}	1.6094 x 10^{6}	1.6094 x 10^{5}	1.6094 x 10^{3}	1.6094
Micro-meter (micron)	3.937 x 10^{-5}	32.808 x 10^{-7}	10.94 x 10^{-7}	62.137 x 10^{-11}	1	1 x 10^{-3}	1 x 10^{-4}	1 x 10^{-6}	1 x 10^{-9}
Millimeter	3.937 x 10^{-2}	32.808 x 10^{-4}	10.94 x 10^{-4}	62.137 x 10^{-8}	1 x 10^{3}	1	0.1	1 x 10^{-3}	1 x 10^{-6}
Centimeter	3.937 x 10^{-1}	32.808 x 10^{-3}	10.94 x 10^{-3}	62.137 x 10^{-7}	1 x 10^{4}	10	1	1 x 10^{-2}	1 x 10^{-5}
Meter	39.27	32.808 x 10^{-1}	10.94 x 10^{-1}	62.137 x 10^{-5}	1 x 10^{6}	1 x 10^{3}	1 x 10^{2}	1	1 x 10^{-3}
Kilometer	3.927 x 10^{4}	32.808 x 10^{2}	10.94 x 10^{2}	62.137 x 10^{-2}	1 x 10^{9}	1 x 10^{6}	1 x 10^{5}	1 x 10^{3}	1

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired unit.

Table C-5. CONVERSION FACTORS--AREA

Given units \ Desired units	Square inch	Square foot	Square yard	Square mile (Statute)	Acre	Square centimeter	Square decimeter	Square meter	Square kilometer
Square inch	1	6.9444 $\times 10^{-3}$	77.1605 $\times 10^{-5}$	2.49 $\times 10^{-10}$	15.94 $\times 10^{-6}$	6.452	6.452 $\times 10^{-2}$	6.452 $\times 10^{-4}$	6.452 $\times 10^{-10}$
Square foot	144	1	0.1111	3.587 $\times 10^{-8}$	2.296 $\times 10^{-5}$	929.0341	929.0341 $\times 10^{-2}$	929.0341 $\times 10^{-4}$	929.0341 $\times 10^{-10}$
Square yard	1296	9	1	3.228 $\times 10^{-7}$	2.066 $\times 10^{-4}$	83.61 $\times 10^{2}$	83.61	83.61 $\times 10^{-2}$	83.61 $\times 10^{-3}$
Square mile (Statute)	40.144 $\times 10^{8}$	2.788 $\times 10^{7}$	3.098 $\times 10^{6}$	1	640	2.589998 $\times 10^{10}$	2.589998 $\times 10^{8}$	2.589998 $\times 10^{6}$	2.589998
Acre	62.73 $\times 10^{7}$	4.3560 $\times 10^{4}$	4840	15.625 $\times 10^{-4}$	1	4046.873 $\times 10^{4}$	4046.873 $\times 10^{2}$	4046.873	4046.873 $\times 10^{-6}$
Square centimeter	15.5 $\times 10^{-2}$	10.764 $\times 10^{-4}$	1.1960 $\times 10^{-4}$	3.8610 $\times 10^{-11}$	2.471 $\times 10^{-8}$	1	1 $\times 10^{-2}$	1 $\times 10^{-4}$	1 $\times 10^{-10}$
Square decimeter	15.5	10.764 $\times 10^{-2}$	1.1960 $\times 10^{-2}$	3.8610 $\times 10^{-9}$	2.471 $\times 10^{-6}$	1 $\times 10^{2}$	1	1 $\times 10^{-2}$	1 $\times 10^{-8}$
Square meter	15.5 $\times 10^{2}$	10.764	1.1960	3.8610 $\times 10^{-7}$	2.471 $\times 10^{-4}$	1 $\times 10^{4}$	1 $\times 10^{2}$	1	1 $\times 10^{-6}$
Square kilometer	15.5 $\times 10^{8}$	10.764 $\times 10^{6}$	1.1960 $\times 10^{6}$	3.8610 $\times 10^{-1}$	2.471 $\times 10^{2}$	1 $\times 10^{10}$	1 $\times 10^{8}$	1 $\times 10^{6}$	1

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired unit.

Table C-6. CONVERSION FACTORS--FLOW

Given units \ Desired units	M^3/sec	M^3/min	M^3/hour	ft^3/sec	ft^3/min	ft^3/hour	L/sec	L/min	cm^3/sec	cm^3/min
M^3/sec	1	60	3600	35.3144	21.1887×10^2	12.7132×10^4	999.973	59.998×10^3	1×10^6	6×10^7
M^3/min	0.0167	1	60	0.5886	35.3144	21.189×10^2	16.667	999.973	16.667×10^3	1×10^6
M^3/hour	2.778×10^{-5}	16.667×10^{-3}	1	98.90×10^{-4}	0.5886	35.3144	27.777×10^{-2}	16.667	2.777×10^2	1.666×10^4
ft^3/sec	28.317×10^{-3}	1.699	101.94	1	60	3600	28.316	16.9896×10^2	2.8317×10^4	1.699×10^6
ft^3/min	4.7195×10^{-4}	28.317×10^{-3}	1.699	16.667×10^{-3}	1	60	47.193×10^{-2}	28.316	4.7195×10^2	2.8317
ft^3/hour	7.8658×10^{-6}	4.7195×10^{-4}	28.317×10^{-3}	2.778×10^{-4}	16.667×10^{-3}	1	7.866×10^{-3}	0.4719	78.650	4.7195×10^2
L/sec	1.000027×10^{-3}	6.00016×10^{-2}	3.6	35.316×10^{-3}	2.11896	127.138	1	60	1000.027	16.667
L/min	1.6667×10^{-5}	1.000027×10^{-3}	6.00016×10^{-2}	5.886×10^{-4}	35.316×10^{-3}	2.11896	1.6667×10^{-2}	1	16.667	1000.027
cm^3/sec	1×10^{-6}	6×10^{-5}	3.6×10^{-3}	3.5314×10^{-5}	2.1189×10^{-3}	1.271×10^{-3}	9.99973×10^{-4}	5.9998×10^{-2}	1	16.667×10^{-3}
cm^3/min	1.6667×10^{-8}	1×10^{-6}	6×10^{-5}	5.886×10^{-7}	0.3531×10^{-4}	2.11887×10^{-3}	5.9998×10^{-2}	9.99973×10^{-4}	60	1

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired unit.

Table C-7. CONVERSION FACTORS--WEIGHT

Desired Units Given Units	Micro-gram	Milli-gram	Gram	Kilo-gram	Grain	Ounce (avdp)	Pound (avdp)	Ton (U.S. Short)	Tonne (metric)
Micro-gram	1	1×10^{-3}	1×10^{-6}	1×10^{-9}	15.4324×10^{-6}	3.5274×10^{-8}	2.2046×10^{-9}	1.1023×10^{-12}	1×10^{-12}
Milli-gram	1×10^{3}	1	1×10^{-3}	1×10^{-6}	15.4324×10^{-3}	3.5274×10^{-5}	2.2046×10^{-6}	1.1023×10^{-9}	1×10^{-9}
Gram	1×10^{6}	1×10^{3}	1	1×10^{-3}	15.4324	3.5274×10^{-2}	2.2046×10^{-3}	1.1023×10^{-6}	1×10^{-6}
Kilogram	1×10^{9}	1×10^{6}	1×10^{3}	1	15.4324×10^{3}	35.274	2.2046	1.1023×10^{-3}	1×10^{-3}
Grain	64.799×10^{3}	64.799	64.799×10^{-3}	64.799×10^{-6}	1	22.857×10^{-4}	1.4286×10^{-4}	7.143×10^{-8}	64.799×10^{-9}
Ounce (avdp)	28.349×10^{6}	28.349×10^{3}	28.349	28.349×10^{-3}	437.5	1	62.5×10^{-3}	3.125×10^{-5}	28.349×10^{-6}
Pound (avdp)	453.59×10^{6}	453.59×10^{3}	453.59	453.59×10^{-3}	7000	16	1	5×10^{-4}	153.59×10^{-6}
Ton (U.S. short)	985.185×10^{9}	987.185×10^{6}	987.185×10^{3}	987.185	14×10^{6}	3.2×10^{4}	2000	1	0.907185
Tonne (metric)	1×10^{12}	1×10^{9}	1×10^{6}	1×10^{3}	1.543×10^{7}	3.5274×10^{4}	2204.62	1.10231	1

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired unit.

Table C-8. CONVERSION FACTORS--CONCENTRATION

Given units \ Desired units	$\frac{mg}{M^3}$	$\frac{\mu g}{M^3}$	$\frac{\mu g}{L}$	$\frac{oz.}{ft.^3}$	$\frac{lbs.}{ft.^3}$	$\frac{grams}{ft.^3}$	$\frac{lbs.}{1000\ ft.^3}$	$\frac{grains}{ft.^3}$
$\frac{mg}{M^3}$	1	1000	1.000027	9.989×10^{-7}	6.243×10^{-8}	2.8317×10^{-5}	6.243×10^{-5}	4.37×10^{-4}
$\frac{\mu g}{M^3}$	1×10^{-3}	1	1.000027×10^{-3}	9.989×10^{-10}	6.243×10^{-11}	2.8317×10^{-8}	6.243×10^{-8}	4.37×10^{-7}
$\frac{\mu g}{L}$	.999973	9.99973×10^{2}	1	9.988×10^{-7}	6.242×10^{-8}	2.8316×10^{-5}	6.242×10^{-5}	4.37×10^{-4}
$\frac{oz}{ft.^3}$	1.00115×10^{6}	1.00115×10^{9}	1.00118×10^{6}	1	62.5×10^{-3}	28.349	62.5	4.375×10^{2}
$\frac{lbs.}{ft^3}$	1.602×10^{7}	1.602×10^{10}	1.602×10^{7}	16	1	453.59	1×10^{3}	7×10^{3}
$\frac{grams}{ft.^3}$	3.531×10^{4}	3.531×10^{7}	3.531×10^{4}	3.5274×10^{-2}	2.20462×10^{-3}	1	2.2046	15.43
$\frac{lbs.}{1000\ ft.^3}$	1.602×10^{4}	1.602×10^{7}	1.602×10^{4}	1.6×10^{-2}	1×10^{-3}	453.59×10^{-3}	1	7
$\frac{grains}{ft.^3}$	2.288×10^{3}	2.288×10^{6}	2.288×10^{3}	2.2857×10^{-3}	1.4286×10^{-4}	6.4799×10^{-2}	14.286	1

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired unit.

Table C-9. CONVERSION FACTORS--VOLUME

Given units \ Desired units	Cubic yard	Cubic foot	Cubic inch	Cubic meter	Cubic decimeter	Cubic centimeter	Liter
Cubic yard	1	27	4.6656 x 10^{4}	0.764559	764.559	7.64559 x 10^{5}	764.54
Cubic foot	3.7037 x 10^{-2}	1	1728	2.8317 x 10^{-2}	28.317	2.8317 x 10^{4}	28.316
Cubic inch	2.143347 x 10^{-5}	5.78704 x 10^{-4}	1	1.63872 x 10^{-5}	1.63872 x 10^{-2}	16.3872	1.63868 x 10^{-2}
Cubic meter	1.30794	35.314445	6.1023 x 10^{4}	1	1000	1 x 10^{6}	999.973
Cubic decimeter	1.3079 x 10^{-3}	3.5314 x 10^{-2}	61.023	0.001	1	1000	.99997
Cubic centimeter	1.3079 x 10^{-6}	3.5314 x 10^{-5}	6.1023 x 10^{-2}	1 x 10^{-6}	1 x 10^{-3}	1	9.99973 x 10^{-4}
Liter	1.3080 x 10^{-3}	3.5316 x 10^{-2}	61.025	1.000027 x 10^{-3}	1.000027	1000.027	1

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired unit.

Table C-10. CONVERSION FACTORS--PRESSURE

Desired units / Given units	Atmospheres	Bar	Millibar	In. Hg.	Cm. Hg.	Mm. Hg.	In. H_2O	Lbs./sq. in.
Atmospheres	1	1.0133	1013.3	29.921	76	760	406.788	14.696
Bar	9.8692×10^{-1}	1	1000	29.5296	75.0059	750.059	401.467	14.504
Millibar	9.8692×10^{-4}	.001	1	29.5296×10^{-3}	75.0059×10^{-3}	75.0059×10^{-2}	40.1467×10^{-2}	14.504×10^{-3}
In. Hg.	33.421×10^{-3}	33.864×10^{-3}	33.864	1	2.540005	25.40005	13.595	4.9116×10^{-1}
Cm. Hg.	1.3158×10^{-2}	1.3332×10^{-2}	13.332	39.3701×10^{-2}	1	10	5.35251	19.337×10^{-2}
Mm. Hg.	1.3158×10^{-3}	1.3332×10^{-3}	1.3332	39.3701×10^{-3}	0.1	1	0.535251	19.337×10^{-3}
In. H_2O	2.4583×10^{-3}	2.49086×10^{-3}	2.49086	7.3554×10^{-2}	0.186828	1.86828	1	3.6136×10^{-2}
Lbs./sq. in.	6.8046×10^{-2}	6.8947×10^{-2}	68.947	2.0360	5.1715	51.715	27.673	1

To convert a value from a given unit to a desired unit, multiply the given value by the factor opposite the given units and beneath the desired unit.

Table C-11. CONVERSION FACTORS--TEMPERATURE

Given units \ Desired units	°F	°C	°R	°K
Degrees Fahrenheit	1	.5555 x (°F - 32)	°F + 460	.5555 x (°F-32) + 273
Degrees Centigrade	1.8°C + 32	1	1.8°C + 492	°C + 273
Degrees Rankine	1.8°C + 32 °R - 460	.5555 x (°R - 492)	1	.5555 x (°R-492) + 273
Degrees Kelvin	1.8(°K-273) + 32	°K - 273	1.8(°K-273) + 492	1

To convert a temperature from given units to desired units, use the formula opposite the given units and beneath the desired unit.

Table C-12. CONVERSION FACTORS--TIME (mean solar)

Given units \ Desired units	Second	Minute	Hour	Day	Week	Month	Year
Second	1	1.667×10^{-2}	2.778×10^{-4}	1.157×10^{-5}	1.653×10^{-6}	3.805×10^{-7}	3.171×10^{-8}
Minute	60	1	1.667×10^{-2}	6.944×10^{-4}	9.920×10^{-5}	2.283×10^{-5}	1.903×10^{-6}
Hour	3600	60	1	4.166×10^{-2}	5.951×10^{-3}	1.370×10^{-3}	1.142×10^{-4}
Day	8.64×10^{4}	1440	24	1	1.429×10^{-1}	3.287×10^{-2}	2.740×10^{-3}
Week	6.048×10^{5}	1.008×10^{4}	1.680×10^{2}	7	1	8.333×10^{-2}	1.934×10^{-2}
Month	2.628×10^{6}	4.380×10^{4}	730	30.42	4.346	1	8.333×10^{-2}
Year	3.154×10^{7}	5.256×10^{6}	8760	365	52.143	12	1